bart
impact
program

IMPACTS OF BART ON AIR QUALITY
INTERIM SERVICE FINDINGS

Street railways S.F. bay area
Air pollution " " " "

new
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The BART Impact Program is a comprehensive, policy-oriented study and evaluation of the impacts of the San Francisco Bay Area's new rapid transit system (BART).

The program is being conducted by the Metropolitan Transportation Commission, a nine-county regional agency established by state law in 1970.

The program is financed by the U. S. Department of Transportation, the U. S. Department of Housing and Urban Development, the National Science Foundation, and the California Department of Transportation. Management of the Federally-funded portion of the program is vested in the U. S. Department of Transportation.

The BART Impact Program covers the entire range of potential rapid transit impacts, including impacts on traffic flow, travel behavior, land use and urban development, the environment, the regional economy, social institutions and life styles, and public policy. The incidence of these impacts on population groups, local areas, and economic sectors will be measured and analyzed. The benefits of BART, and their distribution, will be weighed against the negative impacts and costs of the system in an objective evaluation of the contribution that the rapid transit investment makes toward meeting the needs and objectives of this metropolitan area and all of its people.

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BART IMPACT PROGRAM

IMPACTS OF BART ON AIR QUALITY
INTERIM SERVICE FINDINGS

MARCH 1976

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16. Abstracts

This report documents the findings and methodologies developed during a study of BART's atmospheric impacts. The atmospheric environment for purposes of this study is described by the impact categories of local and regional air quality and microclimate. Assessment included effects on regional air pollutant emissions (CO, RHC, NO_x), station-area carbon monoxide (CO) emissions, and changes in wind direction and velocity.

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PREFACE

The BART Impact Program (BIP) is a comprehensive, policy-oriented study and evaluation of the impacts of the new San Francisco Bay Area Rapid Transit System (BART). The system's alignment and configuration are shown on the page following this preface. The BART Impact Program covers the entire range of potential rapid transit impacts, with major projects covering impacts on traffic flow, travel behavior, land use and urban development, economics and finance, social institutions and lifestyles, public policy and the environment. The incidence of these impacts on population groups, local areas, and economic sectors is being measured and analyzed. The benefits of BART, and their distribution, are being weighed against the negative impacts and costs of the system in an objective evaluation of the contribution that the rapid transit investment makes toward meeting the needs and objectives of the Bay Area and all of its people.

The Environment Project focuses on the effects of BART's physical presence on its surroundings. Environment is defined broadly to include five components: acoustic, atmospheric, natural, social and visual. Within each of these components the Environment Project will address two related phenomena:

- Direct and indirect physical effects upon the environment brought about by the BART system
- Social and psychological consequences of these physical changes to the environment

This report - Impacts of BART on Air Quality, includes an assessment of effects on regional air pollutant emissions, station-area carbon monoxide (CO) emissions, and changes in wind and temperature. It is a working paper containing a detailed presentation of atmospheric findings and the study methodology employed. This report is an interim document as study of BART's atmospheric impacts is continuing. Phase I, covered in this report, concentrated on BART's atmospheric effects on the physical dimensions of the Bay Area. However, measurements and assessment were made under interim BART operations. In Phase II additional assessment will be made as operational conditions change. Also in Phase II, people who live and work next to the BART system will be studied as to how they perceive and respond to impacts. And finally, in Phase II a comparison of BART's impacts with those of other means of providing a similar level of public transportation service will be made. The findings as presented here formed part of the basis for the development of Phase I conclusions regarding BART's overall environmental impacts. These interpretations are reported in the Phase I report - Environmental Impacts of BART: Interim Service Findings.

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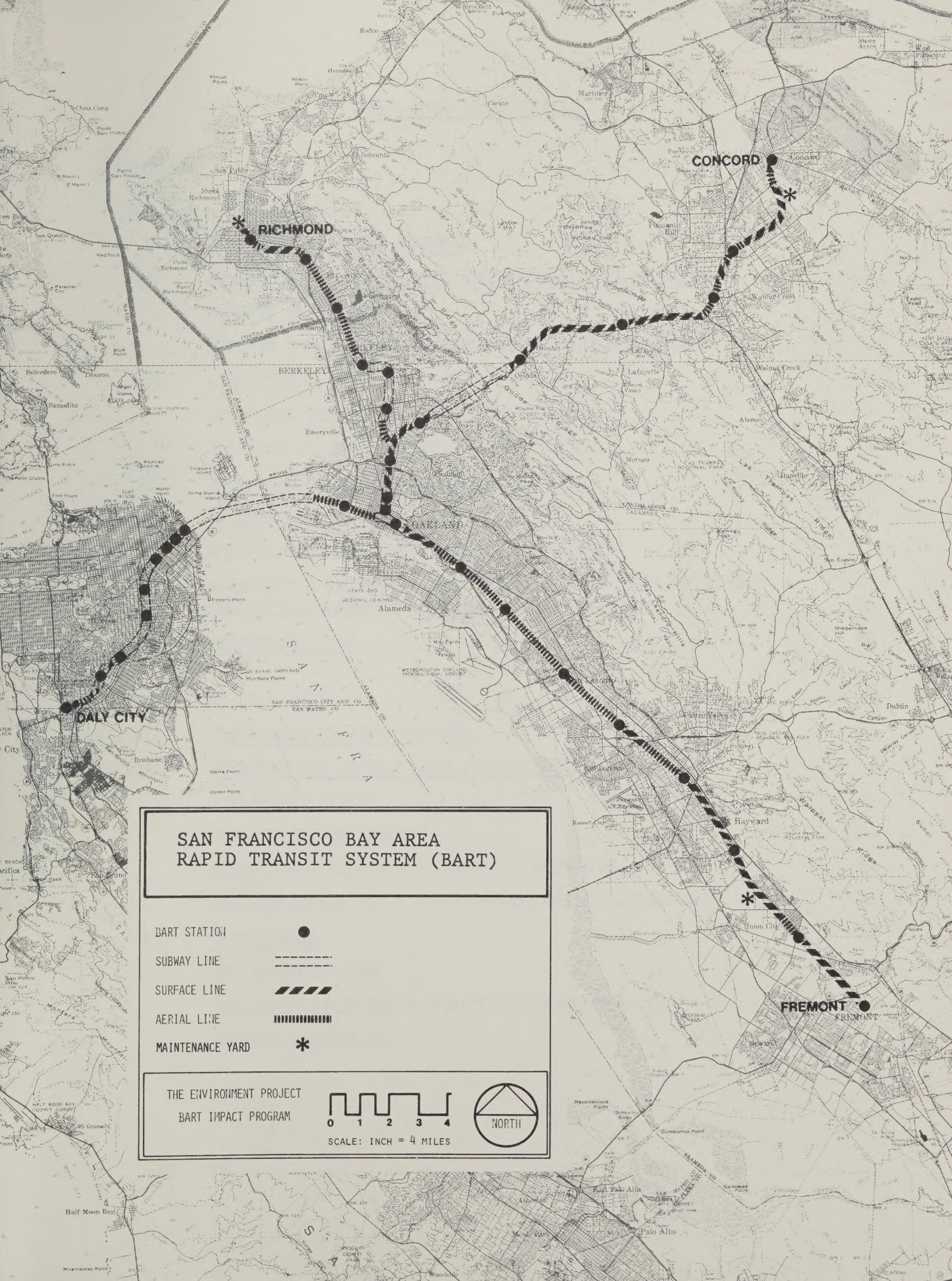
SAN FRANCISCO BAY AREA
RAPID TRANSIT SYSTEM (BART)
BART STATION
SUBWAY LINE
SURFACE LINE
AERIAL LINE
MAINTENANCE YARD
THE ENVIRONMENT PROJECT
BART IMPACT PROGRAM
0 1 2 3 4
SCALE: INCH = 4 MILES
NORTH
RICHMOND
CONCORD
DALY CITY
FREMONT
BERKELEY
OAKLAND
Alameda
Hayward
Walnut Creek
Lafayette
Orinda
Emeryville
Albany
Dublin
Union City
Palo Alto
Menlo Park
Half Moon Bay
Sausalito
Tiburon
Belvedere
Brisbane
Martinez
Pleasant Hill
Danville
Moraga
San Ramon
Castro Valley
San Leandro

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SUMMARY

INTRODUCTION

The atmospheric environment for purposes of this study is described by the impact categories of local and regional air quality and microclimate. Assessment included effects on regional air pollutant emissions, station-area carbon monoxide (CO) emissions and changes in wind direction and velocity.

Air quality impact assessment is a rapidly changing field. Since this study was initiated in 1974, a number of important changes have taken place in air pollution control and evaluation procedures which may affect the findings of this study. These changes could incrementally influence some of the specific magnitudes of the impacts projected, but probably would not cause conclusions drawn from the analysis to be altered.

Important factors which deserve consideration in any future air quality assessments are:

- Improved motor vehicle emission factors which incorporate "cold start" and "hot soak" components explicitly in estimating vehicular emissions.

- The relative importance of trips and VMT to the overall contribution of motor vehicles to both localized and regional air quality.

These and other air pollution developments will be qualitatively described and considered in Phase II.

REGIONAL AIR QUALITY

One of the possible consequences of a rapid transit system such as BART is to divert people from autos to transit, and thus reduce the number of vehicle miles traveled (VMT). As a result, the region's levels of automobile-generated air pollutants decrease. These include carbon monoxide (CO), reactive hydrocarbons (RHC), and oxides of nitrogen (NO_x).

However, BART is not a pollution-free mode of transportation. The entire system requires electrical energy in order to function, and the power plants supplying that energy emit air pollutants. Thus, to properly assess BART's influence on changing air quality in the San Francisco Bay Area, it was necessary to consider both the reduction in automotive emissions and the increase in emissions due to power plants supplying BART's electrical energy.

Methodology

BART's impact on automobile emissions was computed to be approximately proportional to the reduction in VMT caused by the shift of travelers from autos to BART. This required estimates of several factors, including total vehicular pollutant emissions for the region, total regional VMT, and the BART-induced VMT reduction.

Total regional emissions were calculated for 1972, the last year before BART began operations, because this was the latest year for which the detailed auto age and type data required were available. These data were used in a model based on federal Environmental Protection Agency procedures, the Vehicle Emissions Model (VEM), yielding emission factors in grams per mile for CO, RHC, and NO_x (pp. 10-15).

These factors were multiplied by the estimated regional VMT for 1972 to produce estimates of total vehicular pollutant emissions for the region. The regional VMT was estimated by interpolation from MTC model projections for 1970 and 1980 (p. 16).

In estimating BART's impact on VMT, the system's projected ultimate patronage of 200,000 riders per day was used. This figure was adopted in lieu of the present interim-service patronage in order to allow an estimate of BART's maximum rather than interim effect on travel. This was translated into total BART traveler mileage by multiplying by trip lengths from BART station-to-station projections. Adjustments were applied for the proportion of BART travelers diverted from autos (from BART traveler surveys) and auto occupancy. The resulting maximum BART-induced VMT reduction was approximately 3 percent.[1]

This 3 percent reduction was applied to the 1972 regional emissions estimates to produce the desired estimates of emissions reductions attributable to BART. Given the several assumptions involved, these estimates are conservative; that is, actual 1975 emissions reductions are substantially smaller, and future reductions are very unlikely to be higher than these figures.

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[1] The VMT reduction was based on a total daily VMT of 25,153,000 for the three-county BART service area. The estimated average weekday reduction in VMT represented by projected BART ridership diverted from autos is 861,800. Thus, the percent reduction if BART had been running at its full service level in 1972 would be 861,800/25,153,000 or 3.4 percent (pp. 16-19).

Issues and Findings

What is BART's impact on reducing regional air pollutant levels?

BART's diversion of auto users to transit has resulted in some, but a relatively small, decrease in auto-generated air pollutants. For the three counties (San Francisco, Alameda, Contra Costa) in which BART operates, based on the estimated 3 percent BART-induced reduction in VMT, a 3 percent reduction in emission of reactive hydrocarbons, carbon monoxide and oxides of nitrogen would be achieved.

For the entire nine-county Bay Area airshed, the estimated influence of BART on VMT and emissions was even smaller, amounting to less than 1.5 percent of the regionwide emissions.

These percent reductions translate into the following quantities of reduction in pollutants:

CO:	32 tons per day
RHC:	5 tons per day
NO_x:	4 tons per day

One way of viewing the effect of the estimated reductions is to relate them to the goals of EPA's required emission reductions (to achieve the National Ambient Air Quality Standards) as called for in the Control Strategy for the San Francisco Bay Area.[1] The numbers indicated in Table A apply to mobile sources only in the three-county area in which BART operates.

[1] TRW, Inc. (1973), Air Quality Implementation Plan Development For Critical California Regions: San Francisco Bay Area Intrastate AQCR, Washington, D.C.: Environmental Protection Agency.

TABLE A
RELATIONSHIP OF BART-INDUCED POLLUTANT REDUCTIONS TO EPA-REQUIRED REDUCTIONS

Pollutants Produced	EPA-Required Reductions	BART-Induced Reductions
CO: 1073 tons/day RHC: 168 tons/day NO_x: 141 tons/day	CO: 504 tons/day RHC: 131 tons/day NO_x: None required	CO: 32 tons/day RHC: 5 tons/day NO_x: 4 tons/day

Clearly, BART's positive impact on regional air quality has been small. In contrast, it is interesting to note that in the Pre-BART Studies (Residential Environment Impact Study),[1] one of the questions posed to those being interviewed related to the expected effect BART would have on air pollution. Nearly 65 percent of the respondents felt BART would result in less air pollution. This was one of the few questions related to expected environmental impact in which there was a strong positive expectation.

Has BART been responsible for increasing regional pollutants as a result of its energy requirements?

BART's contribution to air pollution, resulting from the power sources required to satisfy its electrical consumption, is negligible. The analysis of energy impact within the Environment Project focused only on regional air quality implications. A fuller analysis of BART's energy-related impacts was done in the Transportation System and Travel Behavior (TS & TB) project.[2] As such, the intention here is to give only a general idea of the order of magnitude of emissions attributable to BART's energy demands and then to compare these with BART's induced emission reductions.

The major factors used to derive the quantity of power plant emissions attributable to BART electricity demands included (pp. 5-6):

1) Total Bay Area consumption of electricity

[1] D. Appleyard, F. Carp et al (1973), Residential Environment Impact Study (Part II, Volumes I-VI), BART II: PRE-BART STUDIES OF ENVIRONMENT, LAND USE, RETAIL SALES, Berkeley: Institute for Urban and Regional Development for the Metropolitan Transportation Commission.

[2] Peat, Marwick, Mitchell & Co. (1975), Analysis of BART's Energy Consumption for Interim System Operations, Berkeley: Metropolitan Transportation Commission.

2) BART's electricity usage

3) Power plant emissions in the Bay Area

It should be noted that the analysis was based on several assumptions, all of which affect the representativeness of the numbers obtained. Among the most important of these assumptions were:

1) Emissions from Bay Area power plants are equally attributable to the electricity demands of all users, including BART

2) Emissions are proportional to power production

Based on these factors and the forecasted BART energy consumption for the full system service,[1] the total system energy for BART would be responsible for the following quantities of pollutants:

CO:	13 lbs/day
RHC:	96 lbs/day
NO_x:	2430 lbs/day

Though BART's net effect on pollutants (production versus reduction) is small in absolute numbers, the reductions due to VMT changes are far greater than the production due to increased electrical energy demands.

TABLE B
BART-INDUCED POLLUTANT REDUCTION AND PRODUCTION

Pollutant	Bart-Induced Reduction	Bart-Induced Production
CO	- 64,000 lbs/day	+ 13 lbs/day
RHC	- 10,000 lbs/day	+ 96 lbs/day
NO_x	- 8,000 lbs/day	+ 2,430 lbs/day

[1] As with VMT reduction data, 1972 numbers for total net production in Northern California and power plant emissions were used. The basis is, therefore, the same in both cases.

The numbers shown in Table B are estimates based on several assumptions as already described. Even allowing for considerable variation from these figures, however, they clearly indicate the very large net differences between BART's induced reduction and generation of pollutants.

LOCAL AIR QUALITY

This portion of the atmospheric impact study consisted of an evaluation of the influence of BART-induced motor vehicle traffic on ambient air quality in the immediate vicinity of BART stations with parking lots, and within the parking lot itself. The former focused on the resident next to BART, the latter on the BART user.

Pertinent issues which were explored in this phase of the study were:

- The nature and intensity of the impact of BART-induced motor traffic on ambient air quality

- The relationship between various attributes of BART station parking lots (capacity, occupancy, congestion, etc.) and air quality

Methodology

For the purposes of this study, local air quality is defined as the ambient air quality in and around BART stations and adjacent areas. Motor vehicle emissions from BART-induced traffic were expected to influence levels of various pollutants in the immediate vicinity of the BART stations. These pollutant types include hydrocarbons, sulfur dioxide, nitrogen oxides, particulate matter, lead, carbon monoxide, and other gases of less significant concern. It was not immediately clear which atmospheric pollutant would be most affected by changes in motor vehicle travel patterns. However, the cause-and-effect relationship between carbon monoxide (CO) concentrations and their origins is known more clearly than that involving other less stable pollutants and their sources. Because of this, CO was selected as the indicator of local air quality.

As it was not practical to provide an analysis for each of the BART stations, it was necessary to select study sites which typify BART station attributes of particular interest in the study. Accordingly, two BART stations were selected as being representative of local extremes with respect to intensity of impact origins (heavy and light BART-induced motor vehicle traffic). The two BART stations selected for study are the North Berkeley Station (low patronage, small parking lot) and the Hayward Station (high patronage, large parking lot, large traffic volume). Both of these sites are removed from any intense non-BART CO sources such as freeways or industrial

manufacturing operations, permitting an analysis of cause and effect without major confounding influences.

The concentration of carbon monoxide in the ambient air was measured using a strip chart recorder connected to an Ecolyzer. Air quality was measured for a one-day period at both the North Berkeley and Hayward Stations. Three locations at both stations were monitored: the BART station and parking lot, downwind from the station (neighborhood site), and upwind from the station (control sites). Measurements at station and neighborhood sites were conducted to provide an indication of the influence of BART on local ambient air quality. Measurements at the control sites were performed to provide a characterization of the baseline ambient air environment - what the station and neighborhood air quality would be if BART were not present (pp. 70-71).

Issues and Findings

What impact does BART have on local air quality within its parking lots?

The hourly concentrations of CO in BART parking facilities are relatively low and well within the 35 ppm[1] hourly limit allowed by the National Ambient Air Quality Standards. The highest level of CO measured at two BART stations was recorded during the morning sampling period at the North Berkeley Station. Particularly stable atmospheric conditions permitted CO buildup during the morning heavy traffic activity, and an hourly high of 10.5 ppm (in both the parking lot and station entrance) was reached in the final hour of monitoring. The greatest hourly concentration of CO recorded at the Hayward Station was measured as 8 ppm at the station entrance in the morning (pp. 39-40).

BART patrons entering the station from the parking lot are subjected at times to short-term (a few minutes) higher exposures of CO (up to 23 ppm). This is due to intermittent congestion in the parking lot causing high levels of CO emissions with subsequent high, short-term, localized CO concentrations.

How does BART impact air quality in the vicinity of BART stations?

The impact of BART-induced motor vehicle traffic on ambient air quality in the vicinity of the BART stations (adjacent neighborhood and control sites) is relatively minor. It is not appreciably different than would have been expected in the same location if BART did not exist.

Measurements indicated significant variations of CO levels within individual control (upwind) sites. These variations were related to CO source activity

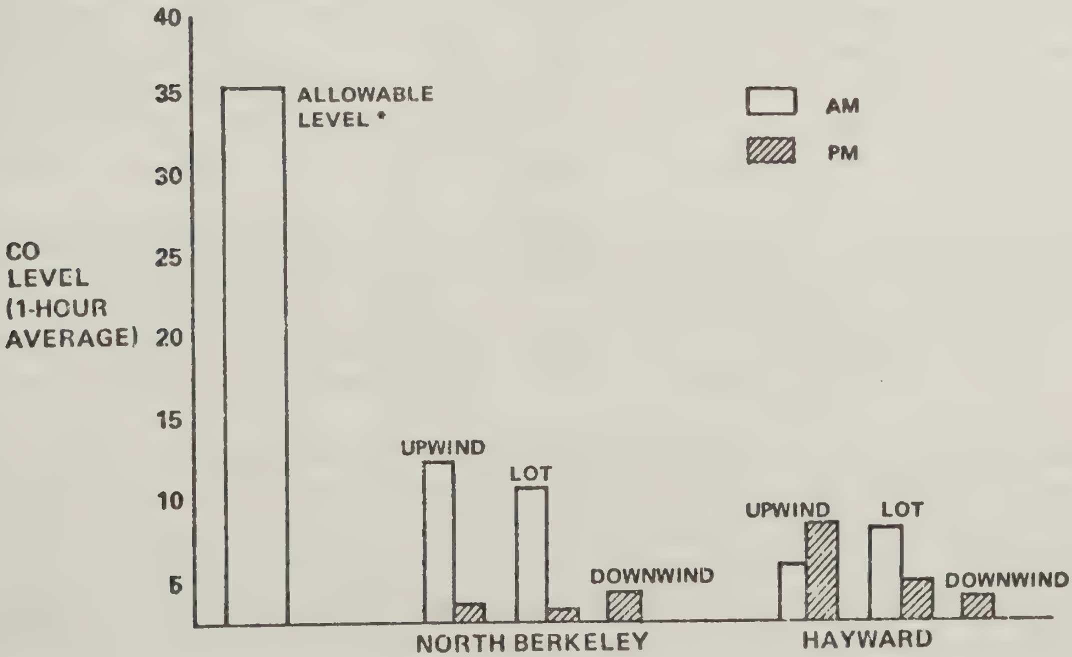
[1] ppm stands for parts per million.

(amount of traffic on adjacent streets) and atmospheric conditions (prevailing wind strength). The peak hourly values of CO measured at the control sites varied from 2.0 to 8.5 ppm at the Hayward locations. At the North Berkeley locations the levels varied from 1.0 to 12.5 ppm (pp. 35-39).

Levels of CO monitored at the neighborhood downwind site adjacent to the Hayward BART parking facilities were found to be somewhat lower than CO levels measured at the control sites. Levels of CO measured at the neighborhood site next to the Berkeley BART parking facility were slightly greater than those at the corresponding Hayward site (a concentration of 4.5 ppm compared to 3.0 ppm). However, this appears to be due more to heavy traffic on a nearby arterial (Sacramento Street) than to the influence of BART parking lot activity (p. 40).

From the limited measurements that were taken, it is evident that BART's effects on local air quality are minimal (Figure A). In some instances (Hayward in the afternoon peak period) the downwind or neighborhood site had lower readings than those of the lot or upwind sites. The North Berkeley downwind site was slightly higher than the upwind or lot sites, but at levels that were not appreciable.

FIGURE A
MAXIMUM 1-HOUR AVERAGE CO LEVELS
IN AND AROUND BART STATIONS



* National Ambient Air Quality Standard—35 ppm for 1 hour.
NOTE: No downwind AM measurements were taken.

What are the major factors affecting the level of pollutants?

The most significant attributes which affect local air quality at a given site in the vicinity of the BART stations were identified as:

1. Meteorological characteristics

2. Traffic activity and behavior in the BART parking lot

3. Proximity to traffic activity

Wind velocity and direction is an important impact determinant affecting local air quality in the vicinity of BART stations (pp. 28-40). During periods of unusually stable atmospheric conditions, ambient concentrations of CO build up steadily over the station parking lot and throughout the adjacent neighborhood.

BART's greatest impact on local air quality occurs during the heavy traffic periods of the morning and afternoon. Because stable atmospheric conditions conducive to pollutant buildup were more frequent in the morning hours, the impact of BART-induced traffic emissions was generally greater there.

However, this phenomenon is not peculiar to areas at BART stations. CO levels at other study sites (control sites) upwind of BART-related traffic were also observed to increase steadily during periods of stable atmospheric conditions.

The atmospheric diffusion rates associated with typical Bay Area atmospheric conditions are apparently sufficient to prevent heavy ambient CO buildup in the vicinity of the BART stations. While ambient concentrations of CO at the stations may be expected to increase somewhat during the heavy traffic periods of the morning and afternoon, the peak levels which occur are generally short term and relatively low in magnitude.

The level of BART-related traffic activity at the BART stations was an important variable in ambient CO levels at the station (pp. 42-48). For a given wind strength and ambient site, a certain level of traffic activity is needed to generate a given ambient level of CO. Peak levels in the parking lot occur coincident with peak levels of parking lot activity.

Air quality in the neighborhood surrounding the BART station is directly related to the level of BART-induced traffic activity on the streets providing accessibility for the BART stations (pp. 48-50). The impact of BART-related street traffic on local air quality is most pronounced in the morning heavy traffic hours when the proportion of all street traffic in the vicinity of the station bound for or departing from the BART station is greatest.

The nature of traffic behavior in the BART parking lot was also an important variable influencing the magnitude of CO emissions. Vehicular emissions of CO differ substantially between the distinct driving cycles associated with motor vehicle behavior at the BART facilities (pp. 50-52), of which the main patterns are:

1. Enter and park
2. Enter and stop, start and exit } Kiss and ride pattern
3. Enter and stop/idle and exit }
4. Cold start and exit (afternoon exit)

Primary determinants of traffic behavior at the BART parking facilities are parking lot occupancy, level of traffic activity and parking lot configuration. Traffic congestion, caused by combinations of these determinants, affects traffic behavior dramatically. Emissions of CO from the vehicles are proportional to the level of traffic congestion, which is measured by frequency of vehicle stops and the duration of travel through the parking lot.

Traffic congestion does not increase appreciably with increasing lot occupancy. The small amount of congestion observed is apparently attributable to the parking lot design, which features separate access ways to the multiple lot segments, spacious parking lanes, and a central station entrance.

Proximity to traffic activity was a consistent determinant of CO levels. The highest levels of CO (12.5 ppm) were found in the parking lot near the entrance to the BART station. Levels of CO observed at sites in the area surrounding the BART station are generally highest at the sites near a major traffic arterial.

Street level ambient concentrations of CO diminish rapidly with distance from the impact origin. Variations in CO concentrations in the vicinity of the BART stations are related to CO source activity in the immediate area of the sampling site. The highest CO levels were consistently found at the sites near the more heavily traveled streets.

MICROCLIMATE

The construction of BART has resulted in alterations to existing land use patterns and individual structures in order to locate the line (aerial and berm configuration), station facilities, parking lots and other BART-related facilities. Neighborhoods have witnessed both the removal of entire blocks of houses and the emplacement of structures where none previously existed. These changes were examined to evaluate their possible effect on modifying local microclimate.

Methodology

For the purposes of this study, microclimate was defined as meteorological phenomena, such as wind and temperature, whose scale of analysis is in the order of magnitude ranging from a few square meters to a square kilometer. The evaluation of the impact of BART structures and open space on wind conditions was conducted by a trained meteorologist and is based on his professional judgment. Temperature impact evaluation was made from actual field measurements. The impact of BART on macro-scale meteorology (i. e., the entire Bay Area) was not examined, as the nature and extent of BART structures were judged to be negligible in possibly affecting regionwide temperature and wind conditions.

Issues and Findings

What is the effect of BART facilities on local microclimate?

The primary finding drawing from a sampling of BART conditions is that the effect of BART structures on local microclimate is minimal. The conditions under which some change was found were those from the channeling of wind around the base of elevated stations (such as El Cerrito del Norte) and beneath aerial sections of trackway (such as along Grove Street). In theory, these conditions can result in an approximately 20-30 percent increase in wind velocity experienced in the areas downwind and immediately adjacent to these situations. However, no wind velocity measurements were taken to verify these theoretical projections (pp. 88-89).

Wind that has been disturbed by passage over obstacles, or wind that has been channelized by passage along city streets, tends to become reconstituted after re-entering an open area. These conditions occur at a number of BART station parking lots and in downtown areas where station plaza areas have been created.

In areas previously occupied by buildings and/or vegetation (i. e., trees) which have been cleared to create parking lots or plaza areas, increase in wind velocity is likely to be experienced (p. 89). These obstacles acted as a wind barrier and, with their removal, the wind which has been disturbed by passage over other structures tends to reconstitute itself in the open area. Buildings or people facing the wind at the end of parking areas or plaza spaces could be subjected to wind velocities as much as 30 to 50 percent higher than they had previously experienced.

Where large parking lots are divided into a number of smaller components (rather than a single lot), and where extensive landscaping was used, the downwind effect could be mitigated by preventing or lessening the reconstitution of wind flow.

What other microclimatological effects could be detected as a result of BART facilities?

BART ventilation facilities are of a negative pressure variety (intake vents). Consequently, there was no observable impact on ambient air temperatures or localized turbulence due to the presence of the vents.

Temperature measurements taken at a number of BART parking lots indicated that there were no significant differences between air temperature over asphalt parking areas as compared to uncovered ground.

Because of the relatively low profile of BART-related structures, the daytime shadows created by those structures have no measurable impact in changing temperatures.

REGIONAL AIR QUALITY

I. DEFINITION AND SCOPE

The San Francisco Bay Area Intrastate Air Quality Control Region (AQCR) has two distinct air pollution problems (MTC, 1975). The two pollutants of concern are carbon monoxide (CO) and photochemical oxidant measured by its ozone (0_3) content. Most ozone is produced as a result of a photochemical process that takes place when reactive hydrocarbons (RHC) and oxides of nitrogen (NO_x) combine in the presence of sunlight. Because the presence of RHC and NO_x is contributed to a great extent by motor vehicles, the 0_3 problem is considered to be primarily caused by them.

One of the possible consequences of a rapid transit system such as BART is to divert people from the use of their personal vehicles to public transit and thus reduce the number of vehicle miles traveled (VMT) by automobiles. As a result, a decrease in automobile-generated pollutants (primarily carbon monoxide, reactive hydrocarbons and oxides of nitrogen) occurs, along with an improvement in air quality.

It must be kept in mind, however, that BART is not a pollution-free mode of transportation. The entire system requires electrical energy in order to function,[1] and the power plants supplying this energy emit air pollutants.[2] Thus, to properly assess BART's effect on changing air quality in the San Francisco Bay Area, it is necessary to consider both reduction in automotive emissions and increase in power plant emissions.

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[1] This report will only consider electrical energy used in the traction vehicles, stations and other facilities. The BART system also uses other sources of energy such as gasoline and diesel fuel (for maintenance vehicles and machinery).

[2] Certain categories of power plants, such as nuclear, geothermal and hydro-electric, do not emit pollutants such as hydrocarbons, carbon monoxide and nitrogen oxides.

II. RESEARCH QUESTIONS AND STUDY STRATEGY

STUDY OBJECTIVES

The overall objectives of the regional air emissions study are to assess the effect BART has on reducing regional air pollutant emissions as a result of decreasing VMT, and to assess the effects of increased air pollution as a result of changes in power production to meet BART's needs.

STUDY STRATEGY AND ASSESSMENT METHODS

While there are methods for evaluating the impact of decreasing VMT on air quality (DIFKIN and SAI models), unfortunately there is presently no simple and inexpensive method. However, a Vehicle Emissions Model (VEM) has been developed which is capable of assessing the effect of decreasing VMT on the emission of pollutants. The basic principle underlying the VEM is the calculation of motor vehicle emissions by using the official federal Environmental Protection Agency procedure (see Chapter V for a detailed explanation).

The power plant emissions attributable to BART demands were estimated based on discussion with the Pacific Gas and Electric Company (PG & E), BART and a literature search.[1] The base (or reference) year for discussion is 1972, as this is the most recent year for which the data necessary to use the VEM is available. Although BART is in only three Bay Area counties (Alameda, Contra Costa and San Francisco), a nine-county area is also considered in the regional air emissions study (the aforementioned three counties plus Marin, Napa, San Mateo, Santa Clara, Solano and Sonoma). This is because these nine counties form an airshed (as specified by the federal Environmental Protection Agency) in which the emissions from any one county affect the air quality in the others. The nine counties also coincide with the area of jurisdiction of the Metropolitan Transportation Commission (MTC).

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[1] A full analysis of BART's energy consumption and evaluation of changes in the Bay Area's requirements for energy will be made by the Transportation System & Travel Behavior (TS & TB) project. The Environment Project's concern is focused on air quality implications.

III. FINDINGS

AUTOMOTIVE EMISSION REDUCTION

The results of the analysis, as expressed in pollutant quantities, are presented in Table 1. The analysis used 3% as an estimate of the reduction in vehicle miles traveled (VMT) for the counties served by BART.[1] The three counties in which BART is located (Alameda, Contra Costa and San Francisco) are presented first. Within these three counties, the reductions would be approximately 3.0% of the emissions from mobile sources for reactive hydrocarbons, carbon monoxide and oxides of nitrogen.

Hydrocarbons (RHC)	:	2.99%
Carbon monoxide (CO)	:	2.98%
Oxides of nitrogen (NO_x)	:	2.83%

If these reductions are viewed in terms of the entire Bay Area airshed (nine counties), the influence of BART-induced emission reductions is even smaller, amounting to less than 1.5% of the regionwide mobile source emissions.

Hydrocarbons (RHC)	:	1.46%
Carbon monoxide (CO)	:	1.46%
Oxides of nitrogen (NO_x)	:	1.48%

These reductions can be related to EPA's required emission reductions (to achieve the National Ambient Air Quality Standards) as called for in the Control Strategy for the San Francisco Bay Area (TRW, June 1973). The numbers indicated in Table 2 apply only to mobile sources in the three-county area in which BART operates.

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[1] Actual VMT reduction figures were not developed when this portion of the study was undertaken. Therefore, for the purpose of this analysis, an estimated 3% VMT reduction (based on data obtained from the Metropolitan Transportation Commission - see pp. 16-20) in Alameda, Contra Costa, and San Francisco counties was used.

TABLE 1

REGIONAL EMISSIONS REDUCTIONS DUE TO BART

County	Freeway VMT (10^3 mi)	Surface Street VMT (10^3 mi)	Emissions from Freeway VMT (tons/day			Emissions from Surface Street VMT (tons/day)			Emission Reductions from Freeway VMT (tons/day)			Emission Reductions from Surface Street VMT (tons/day)		
			RHC	CO	NO_x	RHC	CO	NO_x	RHC	CO	NO_x	RHC	CO	NO_x
Alameda	7006	5850	40.6	235.4	44.1	46	320	28	1.2	7.1	1.3	1.4	9.6	0.8
Contra Costa	3334	2662	19.4	112.5	20.9	21	146.3	12.7	0.6	3.4	0.6	0.6	4.4	0.4
San Francisco	3510	2791	19.3	112.9	22.1	20.8	146.1	13.4	0.6	3.4	0.7	0.6	4.4	0.4
Sub Total	13850	11303	79.3	460.8	87.1	87.8	612.4	54.1	2.4	13.9	2.6	2.6	18.4	1.6
Marin	1618	720	9.2	53.6	10.3	5.5	38.8	3.5						
Napa	30	732	0.2	1	0.2	5.9	41	3.5						
San Mateo	4403	2863	24.5	142.4	27.6	21.6	150.8	13.6						
Santa Clara	4946	6944	28.7	166.1	31.1	54.6	379.6	33.1						
Solano	694	627	4	23.4	4.4	4.9	34.4	3						
Sonoma	589	1494	3.6	20.7	3.7	12.4	85.5	7						
Sub Total	12280	13380	70.2	407.2	77.3	104.9	730.1	63.7						
Totals	26,130	24,683	149.5	868.0	164.4	192.7	1342.5	117.8	2.4	13.9	2.6	2.6	18.4	1.6

TABLE 2
RELATIONSHIP OF BART-INDUCED POLLUTANT REDUCTIONS TO EPA-REQUIRED REDUCTIONS

Pollutants Produced		EPA-Required Reductions		BART-Induced Reductions	
CO:	1073 tons/day	CO:	504 tons/day	CO:	32 tons/day
RHC:	168 tons/day	RHC:	131 tons/day	RHC:	5 tons/day
NO_x:	141 tons/day	NO_x:	None required	NO_x:	4 tons/day

POWER PLANT EMISSION ESTIMATE

To calculate the quantity of power plant emissions attributable to BART electricity demands, an estimation method which employs several simplifying assumptions was used and is explained below.

In 1972, the total net consumption of electricity in the Bay Area was approximately 20,000 million Kwh.[1] According to BART, its 1972 electricity usage was 50.576 million Kwh. Thus, 0.25 percent of the total electricity used in the Bay Area was attributable to BART operations.

Much of this electricity was not produced locally. According to the California Public Utilities Commission,[2] approximately 50 to 55 percent of the electricity consumption in the Bay Area is produced here. For the electricity produced in the Bay Area, all of which was derived from fossil fuels, estimates of power plant emissions were available. According to the federal Environmental Protection Agency, these emissions[3] in the Bay Area for 1972 were (Environmental Protection Agency, 1973):

[1] Source: Pacific Gas & Electric (PG&E), Customer Service Department.

[2] California Public Utilities Commission, Utilities Division, Electrical Branch.

[3] Sulphur oxides (SO_x) were not included in this analysis because in our base year of 1972 electric generation only used clean sulphur content fuels (natural gas or low sulphur content fossil fuels) and therefore was not a significant pollutant. In the future, however, emissions such as sulphur dioxide could be significant as clean sulphur content fuels are replaced by fuel sources with higher sulphur content.

Reactive hydrocarbons (RHC):	0.4 tons/day
Carbon monoxide (CO):	2.9 tons/day
Oxides of nitrogen (NO_x):	74.2 tons/day

Assuming that emissions are proportional to power consumption, the operation of BART is responsible for the following quantities of pollutants:

RHC:	(.0025)	(0.4 tons/day)	(2000 lbs/ton)	=	2.0 lbs/day
CO:	(.0025)	(2.9 tons/day)	(2000 lbs/ton)	=	14.5 lbs/day
NO_x:	(.0025)	(74.2 tons/day)	(2000 lbs/ton)	=	371.0 lbs/day

The discussion on BART's effect on decreasing regional pollutants was based on VMT figures for projected full patronage (200,000 riders per day). To make BART's impact on the production of pollutants comparable, a forecast of BART energy consumption for full system operations was necessary. According to a report prepared as part of another project within the BART Impact Program (Peat, Marwick, Mitchell & Co., 1975), BART's electricity usage for full system service is estimated to be 330 million Kwh per year. Using this BART electrical consumption estimate (but retaining 1972 figures for total Bay Area consumption and power plant emissions in order to be consistent with the use of 1972 vehicular data), BART would be responsible for the following quantities of pollutants:

CO	=	13 lbs/day
RHC	=	96 lbs/day
NO_x	=	2430 lbs/day

It is important to point out that these are pounds per day in contrast to BART-induced reductions reported in tons per day.

It should be noted that the previous analysis was based on several assumptions, all of which affect the representativeness of the numbers obtained. Among the most critical of these assumptions are: (1) emissions from Bay Area power plants are equally attributable to the electricity demands of all consumers, including BART, and (2) that emissions are proportional to power production. This analysis is only intended to give a general idea of the order of magnitude of emissions attributable to BART electricity demands.

In the course of obtaining these estimates, several other interesting facts concerning power generation were learned:

- Like many utility companies, PG & E, which is responsible for supplying electricity to the entire Bay Area, relies on many different sources of electricity generation. Besides fossil fuel

power plants in the Bay Area,[1] consumer demand can be met by hydroelectric power (from the Pacific Northwest and Northern California), power plants not in the Bay Area (such as PG & E's Moss Landing facility) and geothermal power (the Geysers). The quantity of electricity supplied by these sources also varies. For example, in dry years, hydroelectric power is considerably less than during rainy years. Also, not all power generated in the Bay Area is necessarily used there. Because Northern California has historically been able to produce more electricity than it consumes, PG & E-generated power may end up in Southern California (through a complex intertie network of transmission lines) which historically consumes more power than it generates.

- Consumer demand in the Bay Area follows a "bimodal" pattern. In other words, there are normally two peak periods of electricity consumption (early morning and late afternoon), with a fairly constant demand at all other times.

- The manner in which PG & E commits its supply of electricity to satisfy demand is similar to other utility companies. The initial supplier is hydroelectric, followed by steam electric generating units which are committed according to size, as certain units require a longer startup time than others.

- Because of BART's long lead time from conception to operational status, the Pacific Gas and Electric Company has had adequate opportunity to plan for meeting the system's energy demands. This anticipation and planning has apparently minimized the effect of BART requirements on PG & E's ability to meet the demand.

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[1] These are facilities at Pittsburg, Antioch and South San Francisco.

IV. CONCLUSIONS AND IMPLICATIONS

Clearly the effects of BART alone in helping to achieve the National Ambient Air Quality Standards in the San Francisco Bay Area are minimal. Even if BART patronage were to increase to two to three times its present level, with corresponding changes in vehicle miles traveled by automobiles, its effect on reducing polluting emissions regionwide would not be such that it alone could be relied upon to achieve the desired standards. Other studies have confirmed the finding that, in general, rapid transit systems do not reduce VMT sufficiently to greatly affect emissions (TRW, June 1973). Estimates of emissions reduction for the proposed Atlanta Regional Transit System indicate an 8% reduction in total emitted pollutants when the transit system goes into operation (U.S. Department of Transportation, 1973). However, this is based on a projected 8% reduction in vehicle miles traveled (as compared with the estimated 3% for the BART system).

On the other hand, it is apparent that BART-induced power plant emissions are also negligible. Even if BART's electricity consumption is to increase by tenfold, the power plant emissions attributable to BART would only be 2.5% of the total power plant emissions. Just as BART's relative (or percentage) contribution to power plant pollution is minimal, it is also true that the absolute (or tons/day) contribution is similarly negligible. This is only so because a large proportion (approximately 30%) of the Bay Area's electricity is generated by hydroelectric units, which are pollution free. In locations where fossil fuel power plants are the major suppliers (such as Southern California), the absolute contribution imposed by a rapid transit system's electricity demands would be much higher. If such areas are experiencing difficulties in achieving the National Ambient Air Quality Standards, the absolute contribution is of more concern than a relative one.

It is clear, even from the brief analysis undertaken in this study, that rapid transit systems like BART cannot be built with the expectation that an area's air pollution problems will be resolved as a by-product of the development of that system. However, it is equally clear that rapid transit systems can be important components in a package of control measures designed to reduce regional air pollution.

That is, the effect of rapid transit takes on greater significance when combined with other measures such as car-pooling, increased feeder bus service, alternative working hours, land use controls and a whole host of other possible control strategies. Any reduction in emissions, no matter how minor, does help in improving air quality. Even a 3% reduction in VMT/emissions, in conjunction with other control measures, may cause National Ambient Air Quality Standards to be met.

The major factor determining the degree to which BART-like systems will help in solving regional pollution problems is the VMT reductions attributable to the system. There is generally a straight line correlation between the percent of VMT reduced and the percent of reduced mobile source pollution. That is, a 3% reduction in VMT will result in a 3% reduction in <u>mobile source</u> emissions of air pollutants in the area where the VMT reductions take place. However, this does not mean that a 3% reduction in <u>total</u> emissions in the region occurs, as emissions from light duty vehicles do not account for the entire emissions inventory. Other sources such as power plants, industrial facilities and aircraft also play important roles. For example, in Los Angeles County, stationary sources contribute 28% of the total NO_x and 11% of the total reactive hydrocarbon emissions (TRW, March 1975). Unless light duty vehicle emissions constitute an extremely large percent (greater than 90%) of the total emissions, it is incorrect to assume that a certain percentage reduction in VMT will lead to the same percentage reduction of total emissions.

V. METHODOLOGY

VEHICLE EMISSIONS MODEL (VEM)

Air pollutant emissions from motor vehicles emanate from three principal sources: exhaust, crankcase blowby and evaporation from the fuel tank and carburetor. All oxides of nitrogen (NO_x) and carbon monoxide (CO) emissions come from the exhaust pipe, while approximately 55% of the hydrocarbons (HC) come from engine exhaust, 25% from blowby and 20% from evaporation (Environmental Protection Agency, April 1973).

The VEM calculates light duty vehicle[1] exhaust emission factors for hydrocarbons, oxides of nitrogen and carbon monoxide from the following equation:

$$e_{np} = \sum_{i=n-12}^{n+1} \left(C_{ip}\right)\left(d_{ipn}\right)\left(m_{in}\right)\left(S_{ip}\right)$$

where

e_{np} = emission factor in grams/vehicle mile for calendar year n and pollutant p,

C_{ip} = the 1975 federal test procedure emission rate for pollutant p (grams/vehicle mile) for the i-th model year, at low mileage. This is the Environmental Protection Agency's measured pollutant emission rate for a vehicle when it is new (less than 4,000 miles driven) (see Table 3),

d_{ipn} = the controlled vehicle pollutant p emission deterioration factor for the i-th model year at calendar year n, which accounts for increased emissions of pollutant (on a grams/mile basis) from older cars (see Table 4).

m_{in} = the weighted annual travel of the i-th model year during calendar year n, which reflects the fact that newer cars are generally driven more miles per year than older ones.

S_{ip} = the weighted speed adjustment factor for exhaust emission for pollutant p for the i-th model year vehicle. This factor adjusts pollutant emission rates according to average speed (HC and CO emissions decrease with vehicle speed, while NO_x emissions increase - see Figure 1).

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[1] A light duty vehicle is defined as any motor vehicle either designated primarily for the transportation of property and rated at 6,000 lbs. gross vehicle weight or less, or designated primarily for the transportation of persons and having a capacity of 12 persons or less.

TABLE 3

EMISSION FACTORS FOR LIGHT DUTY VEHICLES

Pollutant	Exhaust emission factors at low mileage per model year										
	Pre 1966	1966	1967	1968	1969	1970	1971	1972	1973 through 1974	1975	1976	Post 1976
Carbon monoxide												
g/mi	87	51	50	46	39	36	34	19	19	2.8	1.8	1.8
g/km	54	32	31	29	24	22	21	12	12	1.7	1.1	1.1
Exhaust hydrocarbons												
g/mi	8.8	6.0	4.6	4.5	4.4	3.6	2.9	2.7	2.7	0.33	0.23	0.23
g/km	5.5	3.7	2.9	2.8	2.7	2.2	1.8	1.7	1.7	0.21	0.14	0.14
Nitrogen oxides												
g/mi	3.6	3.4	3.4	4.3	5.5	5.1	3.5	3.5	2.3	1.1	1.1	0.31
g/km	2.2	2.1	2.1	2.7	3.4	3.2	2.2	2.2	1.4	0.68	0.68	0.19

Source : Environmental Protection Agency, April, 1973

TABLE 4

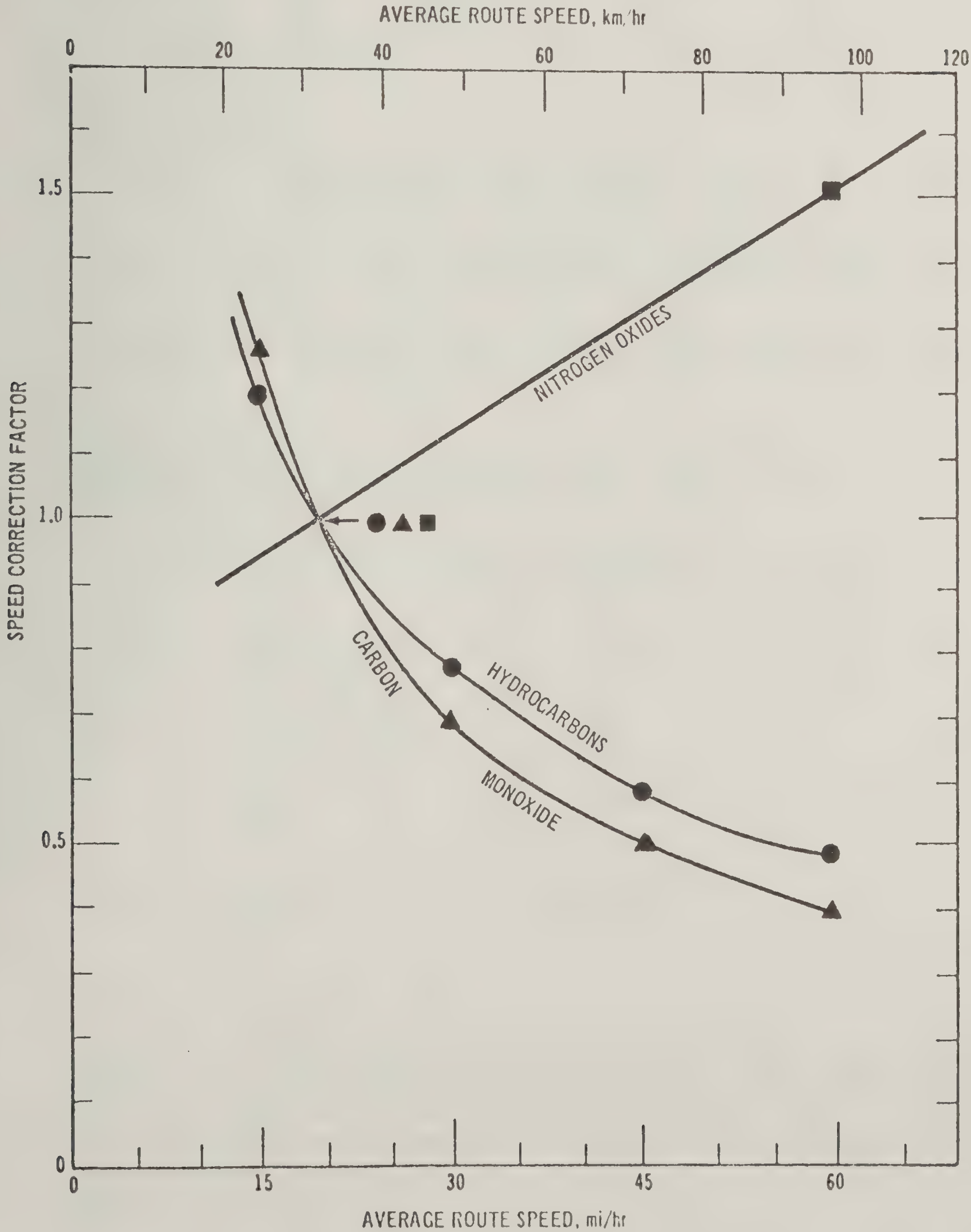
DETERIORATION FACTORS FOR LIGHT DUTY VEHICLES

Pollutant and model year	Vehicle age, years									
	0	1	2	3	4	5	6	7	8	≥9
Carbon monoxide										
Pre-1966	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1966	1.00	1.13	1.21	1.24	1.25	1.28	1.29	1.31	1.32	1.34
1967	1.00	1.11	1.18	1.23	1.29	1.35	1.40	1.46	1.50	1.56
1968	1.00	1.24	1.35	1.41	1.47	1.53	1.58	1.63	1.67	1.72
1969	1.00	1.42	1.53	1.59	1.63	1.68	1.71	1.75	1.79	1.82
1970 through 1974	1.00	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51	1.56
Post-1974	1.00	1.16	1.34	1.50	1.62	1.75	1.88	2.00	2.10	2.22
Hydrocarbon										
Pre-1966	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1966	1.00	1.14	1.22	1.25	1.27	1.29	1.30	1.32	1.35	1.35
1967	1.00	1.07	1.10	1.12	1.14	1.15	1.17	1.18	1.20	1.21
1968	1.00	1.12	1.18	1.21	1.23	1.26	1.28	1.30	1.32	1.35
1969	1.00	1.10	1.16	1.18	1.21	1.23	1.25	1.28	1.29	1.31
1970 through 1974	1.00	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.26
Post-1974	1.00	1.14	1.30	1.44	1.55	1.67	1.77	1.88	1.96	2.07
Nitrogen oxides										
Pre-1970	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1971 through 1974	1.00	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25	1.26
1975	1.00	1.03	1.07	1.10	1.13	1.17	1.19	1.21	1.24	1.26
1976	1.00	1.03	1.07	1.10	1.13	1.17	1.19	1.21	1.24	1.26
Post-1976	1.00	1.17	1.37	1.53	1.67	1.82	1.94	2.06	2.17	2.32

Source: Environmental Protection Agency, April, 1973

FIGURE 1

AVERAGE SPEED CORRECTION FACTORS FOR ALL MODEL YEARS



SOURCE: Environmental Protection Agency (April, 1973)

In addition hydrocarbon emission factors from evaporative and crankcase losses are determined using:

$$f_n = \sum_{i=n-12}^{n+1} (h_i)(m_{in})$$

where

f_n = the combined evaporative and crankcase hydrocarbon emission factor for calendar year n.

h_i = the combined evaporative and crankcase emission rate for the <u>i-th</u> model year (see Table 5).

m_{in} = the weighted annual travel of the <u>i-th</u> model year during calendar year n.

TABLE 5
LIGHT DUTY VEHICLE CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSIONS

Model Year	Grams/Mile
Pre-1961	7.1
1961 through 1963	3.8
1964 through 1967	3.0
1968 through 1969	3.0
1970 through 1971	0.5
1972	0.2
Post 1972	0.2

Source: Environmental Protection Agency (April 1973)

Emissions from heavy duty vehicles were not considered as their effect, relative to the present analysis on emissions levels, is considered negligible compared to that of emissions from light duty vehicles. This is based on the premise that the number of people who previously rode in heavy duty vehicles and who might subsequently shift to a rapid transit system such as BART is negligible.

All light duty vehicles were assumed to be gasoline powered. Calculations were made on a county basis and freeway and surface street (VMT) were considered separately, due to the input requirements of the VEM (specifically the model year distribution and vehicle average speeds). The baseline year chosen was 1972 because of availability of data. Even though BART was not in passenger operation during the year, it was assumed that fully operational system (200,000 riders per day) induced VMT reductions would have occurred in 1972 had BART been in operation. The average speeds used in this analysis were 53 MPH for freeways and 26 MPH for surface streets (national averages).

It should be noted that the speed correction factor for hydrocarbons and carbon monoxide is extremely sensitive to the coverage speeds used, especially at the low end (see Figure 1). For example, if 20 MPH is used instead of 26 MPH, a 20% increase in CO emissions would result (all else remaining constant). However, if 50 MPH instead of 53 MPH is assumed, the change would only be a 3-4% increase in CO emissions.

The initial step in the analysis was to calculate baseline year emissions without VMT reductions induced by BART. This was derived from the VEM, where the output is emission factors (in grams/mile) for HC, NO_x, and CO. To calculate the total quantity of vehicle emissions, the emission factor was multiplied by the total VMT. Then, to arrive at reduction in emissions induced by BART, the amount of reduction in vehicle miles traveled was established. A 3% VMT reduction was used (see computation that follows). The final step in the process was to mathematically relate the VMT reduction to emission reduction.

COMPUTATIONAL BASIS FOR ESTIMATION OF BART-INDUCED REDUCTIONS IN REGIONAL VMT

MTC provided the estimates of BART-induced VMT reduction used in the associated estimates of regional emissions reductions. The basis for the VMT computations follows.

Regional VMT

Regional VMT data came from MTC model projections (1965-1970-1980-1990). 1970 VMT, including trucks, was projected at 51,480,000; for 1980 it was 63,679,000. A straight-line interpolation gives 53,862,000 for 1972, the year covered by the analysis in this report.

Since no truck trips were hypothesized as being displaced by BART (though possibly redistributed over the day), a "truck correction factor" developed by CALTRANS was used, assuming that trucks represent approximately 6% of VMT. CALTRANS used the factor 0.9434. Thus, 53,862,000 x 0.9434 = 50,813,000 is the figure used for VMT by light duty vehicles in 1972.

MTC projections for distribution of VMT among the nine counties and by freeway or non-freeway were available for 1970. It was assumed that the proportionate shares would not be much different for 1972. County-share proportions were first applied to the 50,813,000 figure. Then the freeway/non-freeway shares were applied, specific to each county, since there are substantial differences among counties. The factors were:

		% of County VMT on	
County	Share of VMT	Freeway	Non-freeway
Alameda	25.3	54.5	45.5
Contra Costa	11.8	55.6	44.4
Marin	4.6	69.2	30.8
Napa	1.5	4.0	96.0
San Francisco	12.4	55.7	44.3
San Mateo	14.3	60.6	39.4
Santa Clara	23.4	41.6	58.4
Solano	2.6	52.5	47.5
Sonoma	4.1	28.3	71.7
Total	100.0	51.4	48.6

The figures in Table 1 of this report are based on the above.

Computation of VMT-equivalent for BART Patronage

This computation started with BART's 1975 "full-service" station-to-station projections from their 1971 "Interstation Fare Schedule" report. Each cell of the 33 x 32 triangular matrix was multiplied by the station-to-station distance in miles (to the nearest tenth-mile). This person-mile table was then aggregated to the county level, as shown in Table 6.

TABLE 6
BART FULL-SERVICE PERSON-TRIP-MILES (1975)

Origin County	Destination County: Alameda	Contra Costa	San Francisco
Alameda	322,565	X	889,661
Contra Costa	242,917	3,783	547,446
San Francisco	X	X	143,692
San Mateo (Daly City)	16,950	1,755	79,288
		TOTAL	2,248,057

"X" indicates assumption that no reverse commute trips occur between the counties shown.

From the BART Passenger Profile Surveys I and II, access mode figures by county of BART trip origin were derived:

	County: Alameda	Contra Costa	San Francisco	San Mateo (Daly City)
Drove alone	33.2%	39.6%	16.6%	30.2%
Pooled	9.1	12.2	4.5	15.6

From the Bay Bridge and Caldecott Tunnel, auto occupancy data amassed by ITTE[1] over several years, persons per auto for car pools were derived. A straight 2.5 persons per auto factor for car-pooling was used. The following shows the results of applying this latter factor, along with the mode-of-access factors to the numbers in Table 6:

Origin County	Destination County: Alameda	Contra Costa	San Francisco
Alameda	D-107,100 P- 11,700	X	D-295,400 P- 32,400
Contra Costa	D- 96,200 P- 11,800	D- 1,500 P- 200	D-216,800 P- 26,700
San Francisco	X	X	D- 23,800 P- 2,600
San Mateo	D- 5,100 P- 1,100	D- 500 P- 100	D- 23,900 P- 4,900

D = number of one-occupant vehicles which were diverted to BART

P = number of car-pool vehicles diverted to BART

(NOTE: Directionality is assumed to be the primary commute direction, since no other assumption could be reasonably made from existing data. Thus, it is assumed no one commutes <u>to</u> San Mateo County (Daly City) on BART, and that there is no reverse commute from San Francisco.)

The grand total of VMT equivalent for full BART patronage is 861,000 VMT. This is the estimated average weekday daily volume for full-service BART.

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[1] University of California, Institute of Transportation and Traffic Engineering, now Institute for Transportation Studies.

Computing the BART-induced VMT Reduction

A number of assumptions were implicit here. It was assumed that:

(1) Traveling by BART does not increase the total trip length for motorists, i.e., the trip length to and from the BART station is precisely equal to trip length to and from the hypothetical "auto trunkline" which was used before BART.

(2) BART can only remove vehicles from streets and highways in counties where it operates.

(3) Those vehicles, once removed, no longer contribute to regional VMT at all.

(4) 1972 BART-equivalent VMT would be equal to the expected 1975 VMT-equivalent (i.e., no change in trip-making patterns 1972-75).

(5) No adjustment should be made to VMT to subtract that fraction of regional VMT which could not possibly be served directly by BART (e.g., work trips to the San Jose-Palo Alto area, work trips to the Contra Costa refineries, etc.) even though trip origins may be in BART's "service area".

In summary, the total 1972 VMT for the three BART counties is 25,153,000 (assuming no BART service available). Thus, the percent VMT reduction if BART had been there in 1972 running at its full-service level is 861,800/ 25,153,000 = 3.4%.

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LOCAL AIR QUALITY

VII. DEFINITION AND SCOPE

Public transportation improvement projects which might alter existing travel behavior might also alter the nature of air pollution. In urban areas where the motor vehicle is a principal source of air pollution, changes in private motor vehicle usage may produce significant impacts on the ambient air environment. Since the nature of most public transit improvement projects is to reduce private vehicle usage, the impact on air resources is generally beneficial on an overall regionwide basis. However, certain attributes of a public transit system may result in motor vehicle travel which could generate adverse localized air quality impacts. Careful study and anticipation of both regional and localized air quality effects are prerequisites to the formulation of suitable design criteria aimed at achieving maximum environmental benefits.

The purpose of the study was to determine the impact of BART stations on local air quality. A complete definition of this problem required careful consideration of the terms impact, BART stations, and local air quality. Each of these terms was explored to assign the particular meaning they convey to the study.

Impact concerns the incremental changes that occur due to the impact origins. These changes can only be assessed by comparison of present conditions with those conditions which would exist had BART not been installed. Information is not available to characterize the air quality of the local environment for either the "before" or "after" status of BART. Therefore, it was necessary to formulate a study plan for the generation of new information to permit the appropriate air quality characterizations.

BART stations constitute the impact origin addressed by the study. Each of the various BART stations exercises a role in inducing motor vehicle traffic, and consequently each of the various BART stations may be expected to influence ambient air quality in the local vicinity. Since the attributes of the various BART stations differ, it was necessary to define these differences to permit meaningful relationships to be drawn between air quality levels and BART stations. Predominant BART station attributes which may be quantified or evaluated are parking lot capacity, parking lot configuration, activity levels, and patronage behavior.

Local air quality relates to the ambient air quality in and around BART stations and adjacent areas. Motor vehicle emissions from BART-induced traffic were expected to influence levels of various pollutants in the immediate vicinity of the BART stations. These pollutant types include hydrocarbons, sulfur dioxide, nitrogen oxides, particulate matter, lead,

carbon monoxide, and other gases of less significant concern. It was not immediately clear which atmospheric pollutant would be most drastically affected by changes in motor vehicle travel patterns. However, the cause and effect associated with CO concentrations and their origins is known to be more definitive than that involving other less stable pollutants and their sources. Because of this relationship, CO was selected as an indicator for the air quality characterization of this study.

The report for the study was organized into six chapters. The present chapter serves as an overall introduction and definition of the problem. Chapter VIII presents an identification of the various research questions to be addressed in the study, and provides a summary of the analytical foundation which was established to be responsive to these questions. Chapter IX contains a summary of the study findings, including a background discussion of the study site environments, and a specific characterization of air quality and impact origins. Chapter X provides a discussion of the more significant conclusions and implications based on a synthesis of the study findings. It also provides an identification of unresolved issues and areas for further study strategy. Chapter XI describes in detail the methodology followed in the study. The final chapter, XII, offers study references.

VIII. RESEARCH QUESTIONS AND STUDY STRATEGY

INTRODUCTION

This section provides an identification of the basic research questions to be addressed in the study, including a discussion of the primary considerations underlying their formulation. The section is divided into three main parts. The first part outlines the basic study objectives, the second part provides an identification of the impact origins (sources of air pollution), and the final portion contains a description of the study strategy and the specific research questions which must be addressed before developing the final impact assessments.

STUDY OBJECTIVES

The overall objective of this study was to determine the impact of BART on local air quality. Specifically, this determination consisted of an assessment of the influence of BART-induced motor vehicle traffic on ambient air quality in the immediate vicinity of BART stations. Pertinent issues investigated were:

- The nature, intensity, and significance of the impact of BART-induced motor vehicle traffic on ambient air quality in the immediate vicinity of BART stations.

- The relationship between various impact determinants (meteorology and attributes of the BART stations) and air quality in the immediate vicinity.

IDENTIFICATION OF IMPACT ORIGINS

The qualitative characterization of impact origins at the various BART stations depends on a careful analysis of origin determinants, such as patronage levels, motor vehicle mix, and the behavior of traffic in and around the stations. These determinants were expected to vary significantly from station to station and from hour to hour. In general, for any given station, emission levels were expected to be greatest during the hours of greatest traffic density (presumably 7-9 a.m. and 4-6 p.m.). However, the behavior of peak-period traffic was expected to vary significantly from

morning to afternoon. Consequently, emission levels of CO (and other pollutants) were also expected to differ.[1] In addition, motor vehicle mix may change during different hours of the day, resulting in impact origins which, for a given behavior, will emit at significantly different rates. The variation of pollutant emissions with respect to vehicle type is illustrated in Table 7.

STUDY STRATEGY AND ASSESSMENT METHODS

The assessment of the impact of BART must be determined by comparison of the actual status of the environment to that which would have resulted had BART not been installed (the No-BART alternative). This carries distinct analytical implications for the assessment of local and regional impacts. In developing a regional characterization of the status of the environment for the No-BART alternative, it would be necessary to project the consequences of alternative transportation measures which may have been implemented. However, for the assessment of local impacts associated with specific attributes of BART, the task of characterizing the local No-BART environment corresponds to describing the present environment, minus BART.

In assessing the impact of BART station attributes on local air quality, three basic determinations are prerequisite:

1. Characterization of the existing local air quality in BART station parking lots and the surrounding neighborhood.

2. Characterization of the local air quality in the vicinity of the BART stations had BART not been installed.

3. Characterization of BART station attributes which act as impact determinants.

Several analytical tools are available for application to the first two requirements. However, it has not been clearly demonstrated that these methods are superior to empirical approaches. Consequently, when air quality models are used, empirical methods should be adopted to validate them. Instead, a direct air monitoring approach was adopted, utilizing available technology for CO monitoring.

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[1] The substantial effect of motor vehicle behavior on pollutant emissions is dramatically illustrated in Figure 1 in Chapter V.

TABLE 7

AVERAGE EMISSION FACTORS FOR HIGHWAY VEHICLES

Year	Carbon monoxide		Hydrocarbons: Exhaust		Hydrocarbons: Crankcase and evaporation		Nitrogen oxides (NO_x as NO_2)		Particulates: Exhaust		Particulates: Tire wear		Sulfur oxides (SO_2)	
	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km
1965	89	55	9.2	5.7	5.8	3.6	4.8	3.0	0.38	0.24	0.20	0.12	0.20	0.12
1970	78	48	7.8	4.8	3.9	2.4	5.3	3.3	0.38	0.24	0.20	0.12	0.20	0.12
1971	74	46	7.2	4.5	3.5	2.2	5.4	3.4	0.38	0.24	0.20	0.12	0.20	0.12
1972	68	42	6.6	4.1	2.9	1.8	5.4	3.4	0.38	0.24	0.20	0.12	0.20	0.12
1973	62	39	6.1	3.8	2.4	1.5	5.4	3.4	0.38	0.24	0.20	0.12	0.20	0.12
1974	56	35	5.5	3.4	2.0	1.2	5.2	3.2	0.38	0.24	0.20	0.12	0.20	0.12
1975	50	31	5.0	3.1	1.5	0.93	5.0	3.1	0.38	0.24	0.20	0.12	0.20	0.12
1976	44	27	4.3	2.7	1.3	0.81	4.8	3.0	0.38	0.24	0.20	0.12	0.20	0.12
1977	37	23	3.7	2.3	1.0	0.62	4.3	2.7	0.38	0.24	0.20	0.12	0.20	0.12
1978	31	19	3.2	2.0	0.83	0.52	3.8	2.4	0.38	0.24	0.20	0.12	0.20	0.12
1979	27	17	2.7	1.7	0.67	0.42	3.4	2.1	0.38	0.24	0.20	0.12	0.20	0.12
1980	23	14	2.4	1.5	0.53	0.33	3.1	1.9	0.38	0.24	0.20	0.12	0.20	0.12
1990	12	7.5	1.3	0.81	0.38	0.24	1.8	1.1	0.38	0.24	0.20	0.12	0.20	0.12

NOTE: This table reflects interim standards promulgated by the EPA Administrator on April 11, 1973, and in July 1973.

Since empirical methods were to be used to derive air quality levels, there was a necessity to quantify emission levels from impact origins at the BART stations. Hence, the characterization of BART station attributes (assessment prerequisite #3) would be satisfied by implementing a simple traffic monitoring program.

The CO air monitoring program was to be structured to measure typical ambient levels of CO which would be experienced by persons in the station parking lot, and in the surrounding neighborhood. A characterization of current CO levels (assessment prerequisite #1) was to be attained by a straightforward measurement of the station environment during representative conditions. A characterization of the local CO levels corresponding to the No-BART condition (assessment prerequisite #2) was to be obtained by CO measurement at selected "control sites" within the surrounding community. The control sites are selected so that CO levels measured there would be representative of CO levels to which the public would have been exposed for the No-BART condition. Therefore, control sites were located upwind of CO sources at the BART station.

While CO levels at control sites may have origins independent of CO sources at the BART station itself, it was not clear if CO at the control sites could be presumed independent of CO sources of BART-induced street traffic upwind of these sites. An attempt was made to assess the significance of BART-induced street traffic on control site CO levels by analyzing available transportation data for streets in the vicinity of BART stations.

Because it would be impractical to provide an analysis for each of the BART stations, it was necessary to select study sites which typify the BART station attributes of particular interest in the study. Accordingly, two BART stations were selected to be representative of local extremes with respect to volume of BART-induced vehicular traffic, and therefore quantity of emissions. The two BART stations selected for study are the North Berkeley Station (low patronage, small parking lot) and the Hayward Station (high patronage, large parking lot size, large traffic volume). Both of these sites are removed from any intense CO sources such as freeways or industrial manufacturing operations, permitting an analysis of cause and effect without major confounding influences.

The impact of the two BART stations on local air quality was determined by comparing measurements of CO at the control sites with measurements of CO at the BART stations. Differences in these measurements, whether negative or positive, indicate the incremental air quality impacts resulting from BART. The conclusiveness of these findings may be assessed based on an evaluation of the consistency and reliability of the data. Traffic counts for vehicle activity at each of the stations were analyzed, and an attempt was made to relate CO levels to the measured traffic behavior and to other BART attributes which were to be characterized in the study.

IX. FINDINGS

INTRODUCTION

This chapter provides a discussion of the findings of the study. The first portion of the chapter contains a background perspective of impact determinants, including a general characterization of the ambient environment and parking facility attributes. The second part of the chapter provides a summary of the study results, including a specific characterization of the local air quality (baseline and existing) and impact origins.

DESCRIPTION OF IMPACT DETERMINANTS

Ambient Environment -- North Berkeley Area

From Figure 2, an aerial photograph of the North Berkeley Station and its surrounding area, it can be seen that the North Berkeley Station is located in a totally residential section of the City of Berkeley. To build this station, four blocks of houses were removed and the area was paved over. Since the BART line is underground at this point, the only structures visible are the station entry and a small building containing repair equipment. The station entry is located almost in the center of the four-block area, with parking lots on all sides.

The roadways in the vicinity of the North Berkeley Station are identified in Figure 2. The access road immediately to the east of the station entry constitutes the entryway for the majority of vehicles (buses and automobiles) entering the North Berkeley Station area. The major arterial road in the vicinity of the station is Sacramento Street, which forms the eastern boundary of the station. The corner of Sacramento and Delaware Streets is the only intersection in the immediate area which is controlled by a traffic signal. There are stop signs on Virginia at Sacramento and on Acton at Delaware Street. Other stop signs are located at the BART station exits on Virginia, Delaware, and Acton Streets.

The meteorological conditions experienced in Berkeley are similar to those experienced by other East Bay communities. Coincident with the rainy season are inversion conditions conducive to high ambient concentrations of air pollution. Wind direction is usually from east to west during night and early morning hours, and from west to east by the afternoon. Occasionally during summer months, a large part of the area is covered with fog.

FIGURE 2

AERIAL PHOTOGRAPH OF BART NORTH BERKELEY STATION

The only apparent sources of air pollution in the vicinity of the North Berkeley Station are motor vehicles. Air quality in the nearby area is characterized by relatively low concentrations of pollutants. Figure 3 illustrates the typical daily trend for CO levels in January, February, and March (1974) at a monitoring site in Richmond, approximately 6-1/2 miles northwest from the North Berkeley Station. The air samples at this site are extracted from the atmosphere at an elevation 20 feet above the ground level, approximately 100 feet from a heavily traveled road (13th Street). The monitoring data shown in Figure 3 demonstrate clearly the influence of heavy traffic during the morning and late afternoon hours. The early morning CO levels are significantly greater than the afternoon concentrations, due to the presence of more stable atmospheric conditions in the morning hours.

The magnitude of CO levels at the Richmond monitoring station is typically low. No violations of the federal air quality standards for CO were observed in Richmond in 1974. The maximum 8-hour average for CO at this site in 1974 was 7.0 ppm. The federal standards permit an average CO level of 9 ppm for any 8-hour period, and a 35 ppm CO level for any 1-hour period. It should be noted that atmospheric CO concentrations typically vary significantly within a relatively limited space, and that levels of CO at the Richmond site may not be representative of air quality at the North Berkeley Station. However, since the Richmond monitoring site is located in a residential area similar to that surrounding the North Berkeley site, it is expected that trends (if not absolute levels) measured at the Richmond site closely approximate overall trends of CO levels around the North Berkeley Station.

Ambient Environment -- Hayward Station

The Hayward Station is located in the central business district of Hayward, in an area characterized by a mixture of commercial and residential structures. The station, its parking lots, and the surrounding neighborhood are shown in Figure 4. Construction of the Hayward Station required removal of industrial buildings in the area where parking lots are now located. The BART facilities are elevated at the Hayward Station, with the track running through a strip of land previously used for housing and commercial purposes. Of the streets which are immediately around the station, Watkins, Atherton, A Street, Grand, and C Street are adjacent to commercial activities; Montgomery, B Street, and parts of Atherton and Grand are adjacent to residential areas.

FIGURE 3

HOURLY AMBIENT CO TREND AT APCD DISTRICT MONITORING STATION IN RICHMOND

(BAY AREA APCD, 1974)

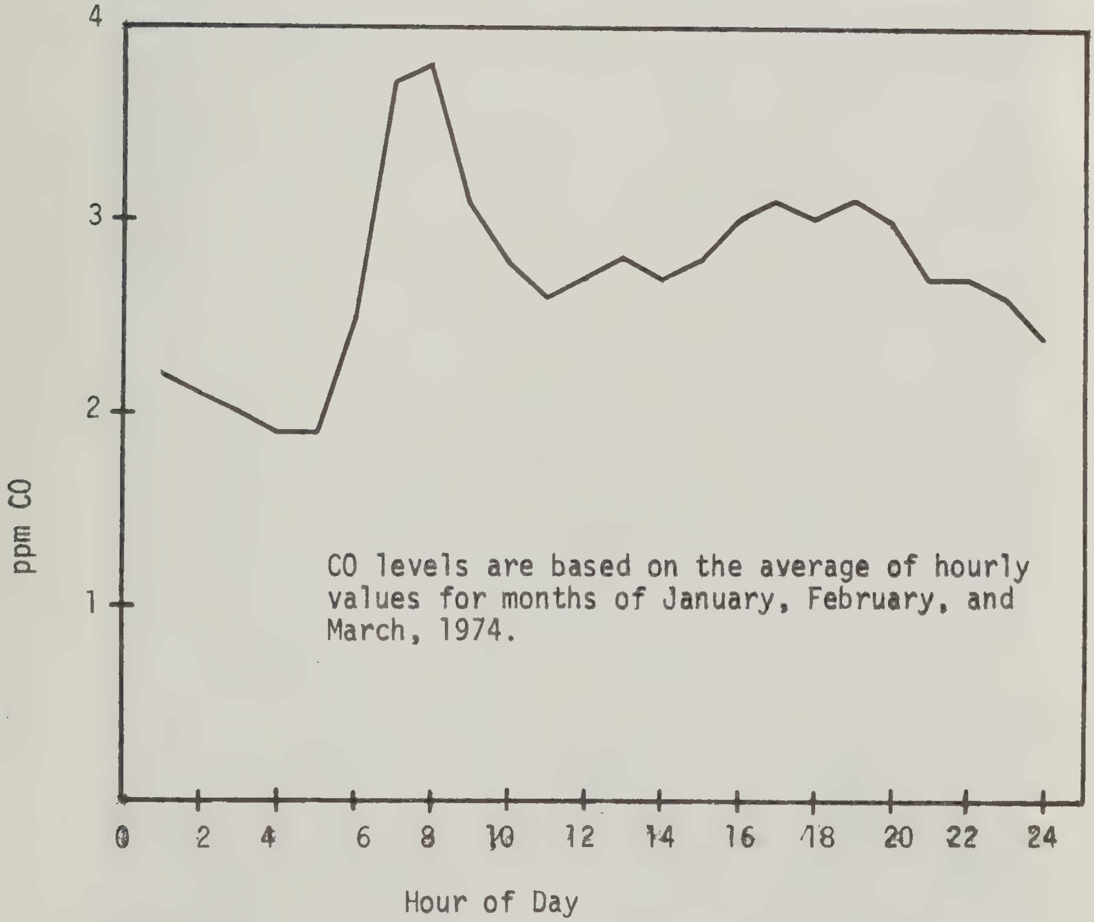


FIGURE 4

AERIAL PHOTOGRAPH OF BART HAYWARD STATION

The corners of Watkins and B Street, Watkins and C Street, Grand and B Street, and Montgomery and A Street are controlled by traffic signals. There are stop signs on Montgomery at B Street, Atherton at B Street, C Street at Atherton, and Atherton at D Street. There are no four-way stops at any intersection close to the station.

The meteorological conditions at Hayward are similar to those at the North Berkeley Station. Inversion conditions conducive to high concentrations of air pollutants are most prevalent during the rainy season. Wind generally originates from the east during the night and early morning and from the west by the afternoon.

The main sources of ambient CO in the vicinity of the Hayward Station are motor vehicles. Figure 5 illustrates the typical daily trend for CO levels in January, February, and March (1974) at the District's nearest air monitoring site in Fremont, approximately 12-1/2 miles south from the Hayward Station. Relative CO trends at the Fremont monitoring site for the purposes of this study were taken to be representative of overall trends of CO levels around the Hayward Station. (Actual magnitudes of CO concentrations were expected to deviate from measurements performed in this study at the Hayward site, since the District's intent is to monitor typical daily exposure concentrations - not street-level, short-term exposures such as those measured in this study.) Figure 5 shows clearly the influence of heavy morning traffic on ambient CO concentrations. The influence of heavy afternoon traffic on ambient CO levels is substantially less dramatic due apparently to the less stable atmospheric conditions associated with the afternoon hours. The magnitude of CO levels at the Fremont monitoring station are typically low. The maximum 8-hour average for CO at this site in 1974 was 7.6 ppm, well within the allowable level specified by the federal air quality standards.

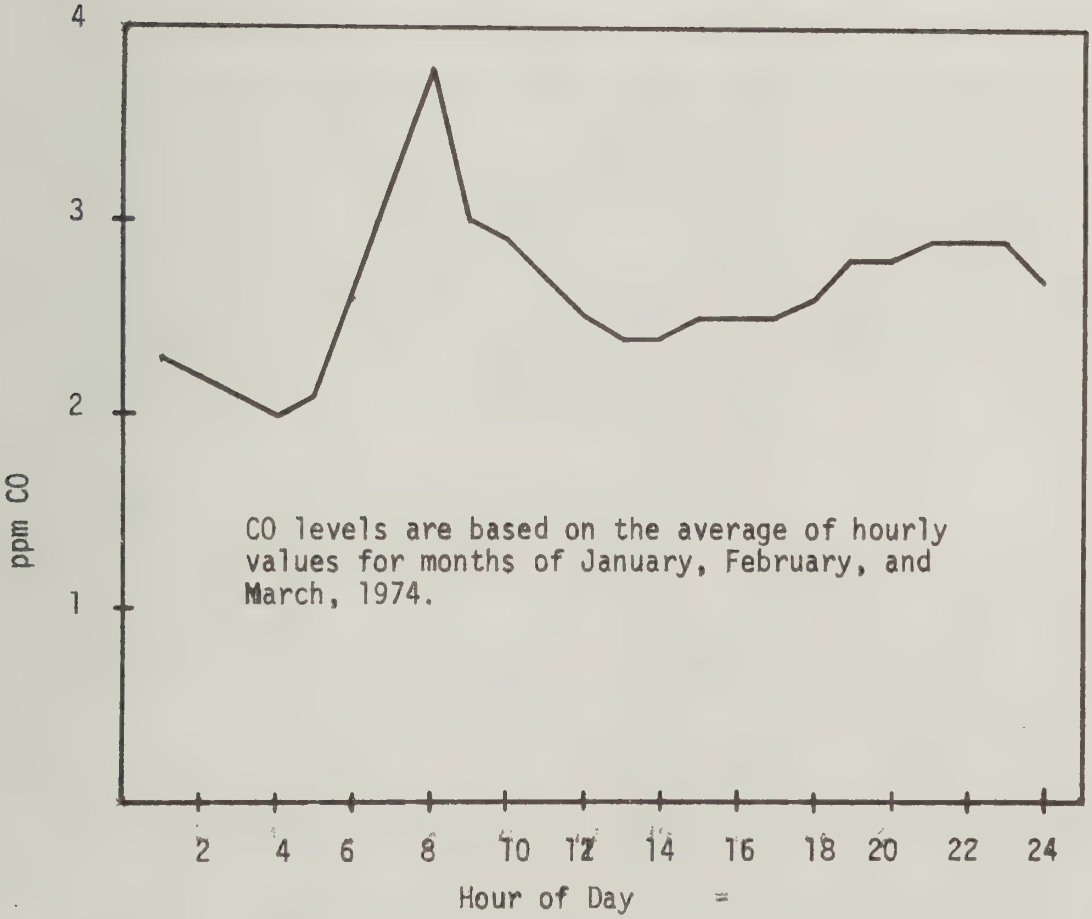
BART Parking Facilities

The total number of available parking spaces at the North Berkeley Station is approximately 500, with the lot adjacent to Sacramento Street being the most heavily utilized (see Figure 2). All driveways can be used as either entrances or exits to the lots. Feeder bus service enters the station area from either the driveway at the corner of Sacramento and Delaware Streets or Sacramento and Virginia Streets. These driveways are also used by most of the automobiles which pick up and drop off passengers ("kiss and ride").

FIGURE 5

HOURLY AMBIENT CO TREND AT APCD DISTRICT MONITORING STATION IN FREMONT

(BAY AREA APCD, 1974)



The capacity of the parking facilities at the Hayward BART Station is 946, or almost twice that of the North Berkeley Station (see Figure 4). Not all the driveways are dual entrance/exits. At the isolated lot west of the station, the driveway at the corner of Grand and C Streets is an exit, while the lot's other driveway is an entrance. The driveway at Montgomery and B Streets is also an entrance, while the two remaining driveways are dual entrance/exits. All feeder bus service enters the station at Montgomery and B Streets and leaves at Atherton and C Streets.

STUDY RESULTS

The following subsections provide a discussion of the results of the monitoring programs which were implemented to characterize the local air quality and the impact determinants. The first subsection provides a summary of air quality monitoring measurements, in terms of variation, trend, and magnitude of CO measured at the various sites. Integrated into this section is a narrative relating meteorology (a major impact determinant) observed at the two station sites to the periods during which air quality measurements were conducted. The second subsection provides the results of the traffic monitoring program utilized to develop a characterization of impact origins.

Air Quality and Meteorology Characterization

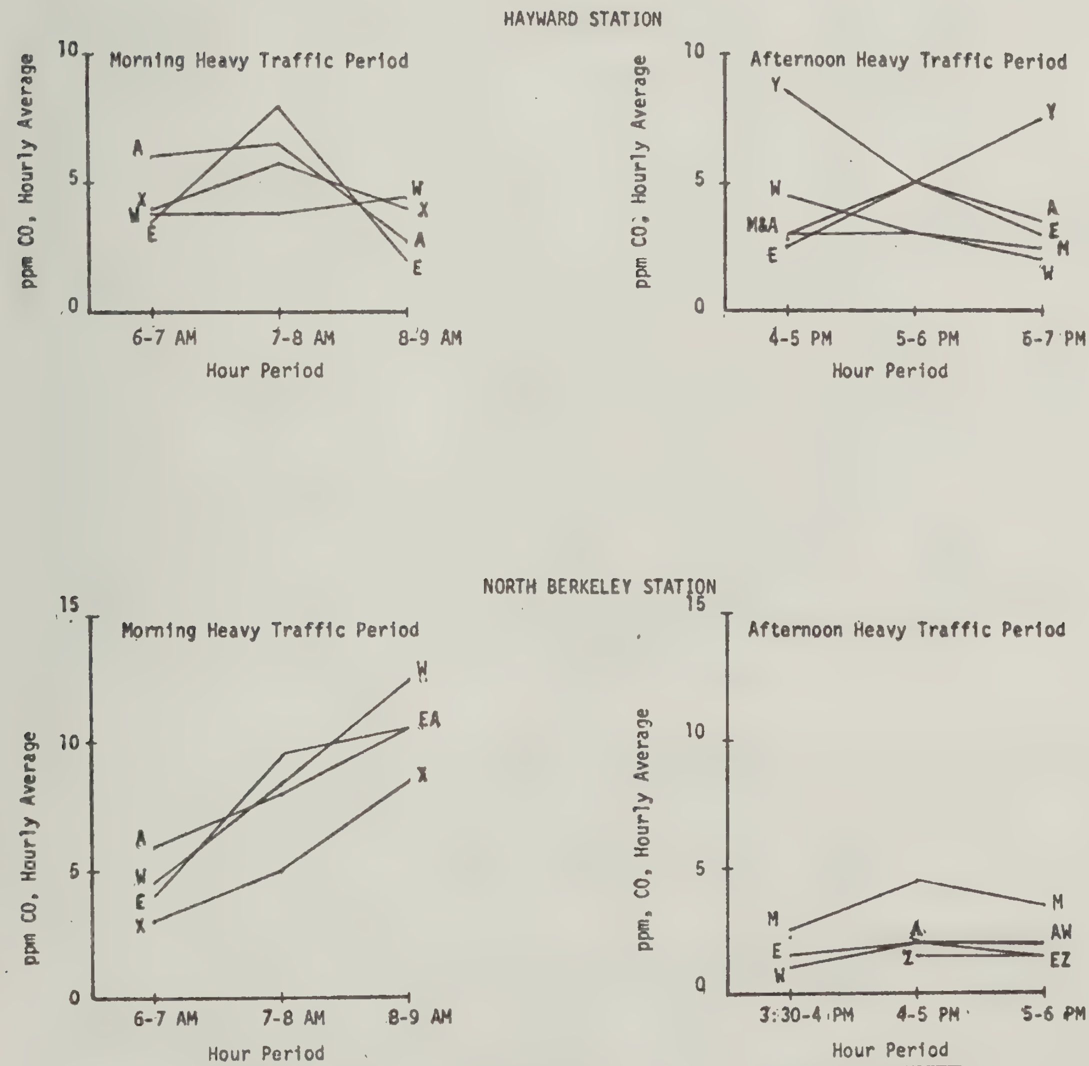
Air quality was measured at three site categories: control sites (sites upwind of BART stations), at the BART station and parking lot, and at impact sites (sites downwind of the BART stations). Measurements at the control sites were performed to provide a characterization of the baseline ambient air environment (the environment for the No-BART condition). Measurements at the BART station and impact sites were conducted to provide an indication of the influence of BART on local ambient air quality. A summary of the air quality measurements conducted during the study is shown in Figure 6. The following discussion provides a summary of the air monitoring measurement at the various study sites, and an identification of the observed meteorological conditions which existed at the BART stations during the air monitoring periods.

Control Sites

Measurements indicated that significant variations often exist between CO levels at selected control sites. These variations are related to CO source activity in the immediate area of the sampling site. The most homogeneous levels of CO measured in the study occurred early in the morning after a low level of CO source activity in the preceding hours had permitted an even mixing of atmospheric CO. During the peak traffic hours, the control sites experienced contrasting levels of ambient CO, with the higher CO levels consistently being measured at the sites near the more heavily traveled streets.

FIGURE 6

AIR QUALITY CHARACTERIZATION DURING PEAK HOUR PERIODS AT THE HAYWARD AND NORTH BERKELEY STATIONS



LEGEND OF SITES:	
E	- Station Entrance
A	- Parking Lot "Walking" Bag Sample
M	- Impact Site (Downwind from BART Station)
W,X,Y,Z	- Control Sites

Figure 6 illustrates the variation of CO levels between the control sites. In the vicinity of the Hayward Station, the homogeneity of early morning ambient pollution is demonstrated, as ambient air at the two control sites measured 3.8 and 4.0 ppm of CO at 7 a.m. At the Berkeley Station, measurements at the two control sites were 3.0 and 4.5 ppm at 7 a.m. However, during the morning heavy traffic hours, measurements of ambient CO at the two selected Hayward control sites differed by as much as 2 ppm (readings of 3.8 and 5.8 ppm at 8 a.m.), and by the late afternoon, the CO in ambient air at the two selected Hayward control sites differed by as much as 5.5 ppm (7.5 ppm and 2 ppm). The highest level of CO measured among selected control sites of either the morning or afternoon sampling periods was consistently associated with the site adjacent to the greater traffic activity. Traffic activity was observed to be greatest on the street adjacent to Control Site Y, followed by the activity adjacent to Control Site X, and then W (Figure 6). Near the North Berkeley Station, the levels of CO at the control sites reflect a more homogeneous distribution of CO emission sources. Afternoon levels for the two control sites at North Berkeley were almost identical, and CO levels at the two morning selected sites differed by a maximum of 4 ppm (12.5 ppm and 8.5 ppm) at 9 a.m. Each of the control sites at North Berkeley were in residential locations, adjacent to streets with relatively little traffic activity. However, Control Sites X and W are both adjacent to Sacramento Street, which was observed to be relatively heavily traveled throughout the day. During the morning sampling period at North Berkeley, the prevailing wind was from the east, so that ambient CO levels at Site W would be affected by emissions on Sacramento Street, but CO levels at Site X would not be affected (either by CO sources on Sacramento Street or other major arterials nearby).

The trend of CO concentrations at the control sites is not clear (Figure 6). In the Hayward monitoring area, hourly CO concentrations rose significantly at Control Site X (from 4 to 5.8 ppm) during the second hour of sampling (7 a.m. to 8 a.m.), but returned to the initial value of 4 ppm at the close of the sampling period (9 a.m.). The CO level at the other Hayward control site (W) remained relatively unchanged throughout the study period. In the North Berkeley monitoring area, hourly CO concentrations rose substantially at both control sites. Control Site W, under probable influence of CO emissions upwind on Sacramento Street, experienced a steady increase in ambient hourly CO concentration from 4.5 ppm in the initial hour (6 to 7 a.m.) to 12.5 ppm in the final hour (8 to 9 a.m.). Ambient CO levels at Berkeley's Control Site X also increased steadily from 3 to 8.5 ppm during the morning test period. It is important to note that atmospheric conditions in the Berkeley area were relatively stable (only very slight air movement was perceivable) during the morning the measurements were conducted, while the conditions observed at Hayward during the preceding day of tests were characterized by slightly greater air movement (a slight breeze was noticeable).

The trend of ambient CO concentration at the control sites during the afternoon heavy traffic hours is less clear than that observed in the morning heavy traffic period. At Hayward, CO levels at Control Site Y are characterized by a substantial decline from 8.5 to 5.0 ppm for the first and second hourly values, ending with an increase to 7.5 ppm in the final hour. During the same period, Control Site W experienced steadily declining ambient CO levels of 4.5, 3.0, and 2.0 ppm, respectively. At the North Berkeley area, a relatively insignificant change occurred in CO levels measured at the two control sites during the heavy afternoon traffic period. It is important to note that atmospheric conditions associated with the afternoon study period were characterized by steady breezes (5 to 10 mph) at both Hayward and North Berkeley.

The magnitude of CO levels measured at each of the control sites during either of the sampling periods appears to be somewhat greater than typical high CO concentrations reported at the nearest District CO monitoring stations. At the Hayward control sites, the highest hourly value of CO reported was 8.5 ppm, and at North Berkeley, a 12.5 ppm hourly CO value was measured. These high CO levels contrast significantly with levels measured at nearby District monitoring stations. The contrast is attributable to differences in siting procedures between the District and this study. The District attempts to measure representative daily population exposures by sampling ambient air at an elevation of 20 feet, and at a location several feet removed from roadways. Air samples analyzed in this study were extracted at five-foot elevations on pedestrian walkways adjacent to streets, and were intended to be representative of "outdoor walking exposures." Numerous studies (SRI, 1971) have demonstrated that CO levels experienced by pedestrians may be several times the average exposure experienced by an individual on a daily or even an hourly basis. Since street level concentrations of CO are more sensitive to local perturbations of CO source activity and because the sampling was limited to a single day, hourly CO trends established at street level are erratic, and do not conform to the pattern developed from air samples at the District monitoring stations.

Peak hourly values of CO measured at control sites in this study were well within the 35 ppm allowable hourly limit specified by the federal ambient air quality standards, and well below levels which induce harmful effects. The primary physiological effect of carbon monoxide in human beings is the reversible combination of CO with blood hemoglobin (Hb) to form carboxyhemoglobin (COHb). The binding of the hemoglobin molecule in this manner prevents it from being able to transport oxygen. Because of metabolic processes, the human body produces endogenous CO which results in a "normal" or "background" level of COHb in the bloodstream of about 0.5 percent. No known adverse physiological effects can be identified for the short-term exposures of CO experienced by patrons at the North Berkeley and Hayward BART Stations. However, an exposure to 10 ppm for eight or more hours results in a COHb level of 2.5 percent, with an associated effect of impairment of time interval discrimination.

BART Station and Parking Lots

Levels of CO within the BART parking lot were generally highest in the middle of the three-hour morning and afternoon monitoring periods. This trend is related mainly to the combination of two factors: (1) the vehicle activity in the BART parking lots, and (2) the meteorology. At the Hayward parking facility, traffic activity is substantially greater during the second hour of the sampling periods than for either the first or third hours. This trend is reflected by the CO profile at the station monitoring site (E) and for the "walking" sample (A) taken through the parking lot (Figure 6). A slight breeze was prevalent over both the sampling periods at Hayward, resulting in local diffusion rates which were apparently sufficient to diminish the level of CO in the parking facility when traffic activity was not sustained at the second hour peak. At the Berkeley Station, morning traffic activity, greatest during the final hour of the sampling period, combined with extremely stable atmospheric conditions during the morning sample period, appears to have permitted the continuous buildup of CO levels measured there (Figure 6). By afternoon, a vigorous and steadily increasing breeze had developed at the Berkeley Station which, in combination with a traffic activity profile similar to that observed at Hayward, resulted in an afternoon CO profile similar to that observed at Hayward.

Hourly CO values measured at the BART station (E) and with a walking sample (A) are similar in trend and magnitude. At Hayward, during the first hour of the morning heavy traffic period, exposure levels of CO were significantly higher for a person walking the parking lot sampling route (6 ppm) than for persons standing at the station entrance (3.5 ppm). However, after the first hour of the morning heavy traffic period, and during the afternoon heavy traffic period as well, there were no significant differences between CO levels measured in the parking lot and at the station entrance. At the North Berkeley Station, during the first hour of the morning sample period, the CO level for the "walking" sample in the parking lot was 6 ppm, in contrast to the level of 4 ppm measured at the station entrance. During the remainder of the morning sampling period, levels of CO at the station entrance were higher or equivalent to CO levels representative of ambient air in the parking lot. During the initial hour of the afternoon monitoring session at North Berkeley, the walking sample in the parking lot was analyzed to be substantially higher in CO concentration than samples measured at the station entrance. This high value is attributable to the fact that only one walking sample was collected in the parking lot during the first hour of the sampling period, and this sample was extracted during an unusually crowded traffic configuration (which included several buses) along the walking route. In the final hours of the heavy traffic period, there were no significant differences between values of CO measured in the parking lot and the station entrance.

The hourly concentrations of CO which the population experienced in either BART parking facility were well within the allowable levels set by the federal ambient air standards. The highest level of CO measured at the two BART stations was recorded during the morning sampling period at the North Berkeley Station. Particularly stable atmospheric conditions permitted CO buildup during the morning heavy traffic activity, and an hourly high of 10.5 ppm (in both the parking lot and station entrance) was reached in the final hour of monitoring. The greatest hourly concentration of CO recorded at the Hayward Station was measured as 8 ppm at the station entrance in the morning.

Impact Sites in Adjacent Neighborhood

Air sampling at the impact sites was conducted at a single location during the afternoon heavy traffic period only. It should be noted that breezes from 5 to 10 mph were prevalent at this time. For each station, the impact site was located directly across a street adjacent to the BART station parking lot. Hence, CO levels measured at the impact sites would tend to reflect the maximum influence which the BART station activities could transmit to the adjacent neighborhoods. Levels of CO monitored at the site downwind of the Hayward BART parking facilities were found to be somewhat lower than CO levels measured at the control sites or at the station (Figure 6). Ambient levels of CO measured at the impact site downwind of the Berkeley BART parking facility were slightly greater (a concentration of 4.5 ppm was measured at the impact site, compared to the next highest value of 2.1 ppm for any parking lot site) than CO levels at control sites or at the station, but this appears to be due more to heavy traffic on Sacramento Street than to the influence of BART parking lot activity. The hourly concentrations of CO at the impact sites were well within the allowable levels (35 ppm for one hour) specified by the federal ambient air standards.

Contrast Between CO Levels at BART Station and Control Sites

During the morning and afternoon sampling periods, measured levels of CO at the BART stations were generally consistent with measured levels at the control sites; however, there were some significant differences in these measurements:

- In the initial hour of the sample period at both Hayward and North Berkeley, the CO exposure levels for a person walking the parking lot sample collection route were significantly higher than CO levels monitored at any of the control sites (during the same period, CO levels at the station entrances were not significantly different than CO levels measured at the control sites).

- The increase in CO levels recorded during the second hour at the two BART stations (both in the parking lot and at the station entrance) appears to be significantly greater than observed during the same time period at the control sites. Also, the magnitude of these CO concentrations at the BART stations appears to be slightly greater than that at the control sites during the second hour of the heavy traffic periods.

- The decline in CO levels recorded during the final hour of the sampling period at the two BART stations appears to be significantly greater than that observed for the same period at the control sites. Also, the magnitude of these CO concentrations at the BART stations appears to be slightly less than that at the control sites during this time frame.

Hence, the monitoring results indicate that, during a portion of the heavy traffic periods, hourly CO levels at the BART stations are likely to peak at slightly higher levels than would be measured at the selected control sites, but that hourly CO levels at the BART parking area are not significantly different from hourly CO levels at control sites during the remainder of the day. It is also evident, from analysis of the "walking" bag sample, that BART patrons entering the station from the parking lot may be subjected at times to short-term (a few minutes) exposures of CO which substantially exceed the expected level of pedestrian exposure at control sites in the adjacent neighborhoods. This is due to inconsistent patterns of traffic activity in the parking lot which, during brief periods of congestion, cause high levels of CO emissions and, subsequently, high short-term localized CO concentrations.

Impact Origin Characterization

The origin of BART-induced CO emissions which impact local air quality in the vicinity of the Hayward and North Berkeley Stations is BART-related motor vehicle traffic. Qualitative and quantitative characterization of this impact origin was obtained by: 1) implementation of a traffic monitoring program which provided vehicle count data for vehicles entering and exiting the parking lots, and 2) observation of traffic behavior by personnel of the air quality monitoring team. A summary of the results of these study efforts is provided in the following subsections.

Vehicle Activity

Figures 7 and 8 illustrate the hourly variation in traffic activity at the two study sites. As had been assumed, the greatest levels of traffic activity at either the Hayward or North Berkeley Station occurred during the heavy traffic periods in the morning and afternoon. As expected, the traffic count data shows that the number of incoming vehicles substantially exceed the number of outgoing vehicles during the heavy morning traffic period, and that outgoing traffic was predominant during the heavy afternoon traffic period. The average overall activity, expressed as the percentage of the parking lot capacity, was nearly the same (approximately 25 percent) for each of the two stations; however, in terms of actual quantities, traffic activity at the Hayward parking lot (260 vehicles/hour) was twice that of the North Berkeley facility (135 vehicles/hour).

While the overall trends of quantities of incoming and outgoing vehicles at both the stations were generally similar, some significant distinctions were apparent:

- The greatest level of morning traffic activity occurred earlier at Hayward than at North Berkeley. At Hayward, morning traffic activity peaked during the 7 to 8 a.m. period, while at the North Berkeley Station, incoming and outgoing traffic increased steadily until peaking during the 8 to 9 a.m. period.

- The balance between incoming and outgoing traffic counts immediately following the peak afternoon traffic activity (the 18th hour at each station) was substantially uneven in the Hayward parking lot, as contrasted with the fairly symmetric balance monitored at the North Berkeley parking lot. After 6 p.m., traffic activity at Hayward consisted predominantly of outgoing vehicles emptying the parking lot. The greatest hourly quantity of vehicles leaving the parking lot at Hayward was recorded between 8 and 9 p.m. By contrast, incoming and outgoing traffic rates at the North Berkeley parking facility decline simultaneously following the peak late afternoon traffic hour.

- Traffic at the North Berkeley parking lot consisted of a substantially higher proportion of through travel ("kiss and ride") than that exhibited at the Hayward Station. In general, the magnitude of the overall disparity between profiles of incoming and outgoing vehicles in Figures 7 and 8 reflects the degree of through travel in the parking lot. At North Berkeley, the level of incoming vehicles is consistent with the level of outgoing vehicles, while at Hayward, the difference between the incoming and outgoing traffic counts is substantial for significant periods during the day.

FIGURE 7

HOURLY TRAFFIC ACTIVITY - NORTH BERKELEY STATION (February 27, 1975)

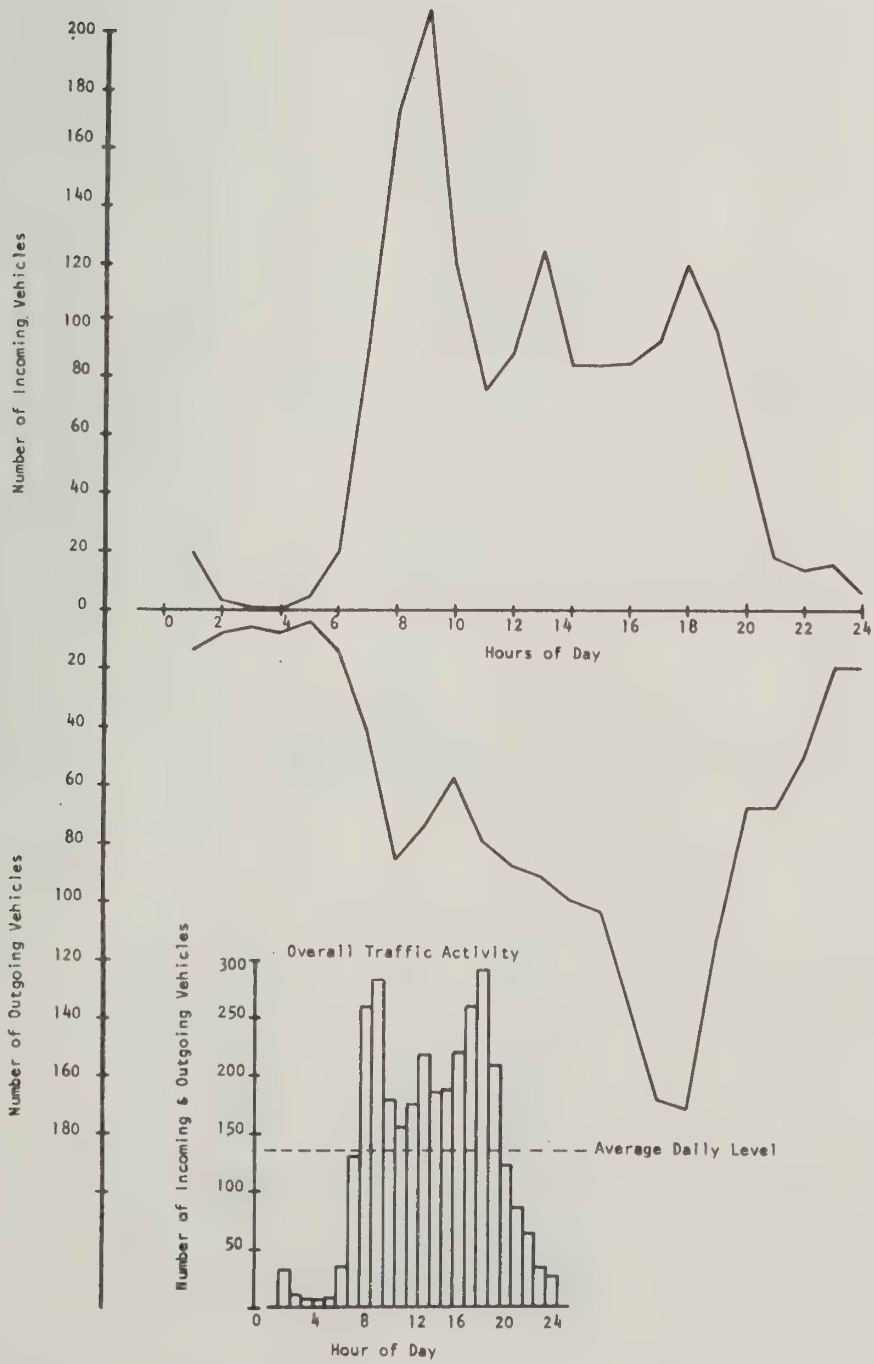
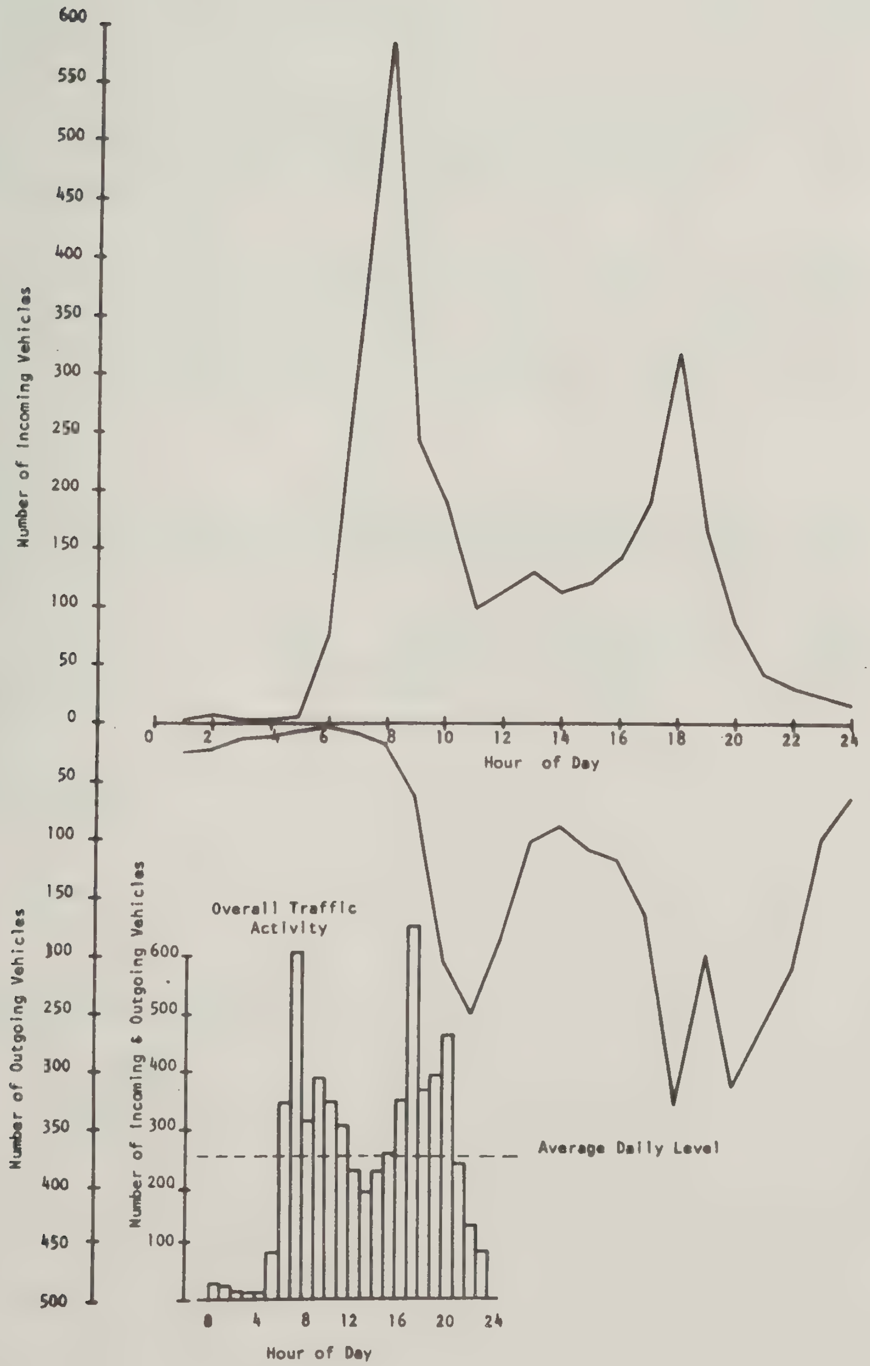


FIGURE 8

HOURLY TRAFFIC ACTIVITY - HAYWARD STATION (February 26, 1975)



- The changes in the level of traffic activity at Hayward were significantly more abrupt than changes monitored at the North Berkeley site.

Parking Lot Occupancy

Figures 9 and 10 illustrate the hourly occupancy rates of the Hayward and North Berkeley Station parking lots. At Hayward, full occupancy was attained in the station parking lot by 8 a.m., and this level was maintained throughout the day until a rapid decline in occupancy began after 3 p.m. At the North Berkeley Station parking lot, a gradual increase in occupancy occurred throughout the day until a peak rate of 75 percent was attained in the 13th hour. Thereafter, occupancy at the North Berkeley parking lot declined steadily for the remainder of the day.

A survey of the model year distribution of vehicles occupying the BART station during the afternoon hours yielded the results shown in Table 8 below. The distribution was found to be essentially the same at each BART parking lot. Approximately one-half of the parked vehicles were 1970 models.

TABLE 8
MODEL YEAR DISTRIBUTION OF VEHICLES OCCUPYING HAYWARD AND NORTH BERKELEY BART PARKING LOTS

BART Station	Percent of Cars in Each Model Year Grouping			
	1950's	Early 1960's	Late 1960's	1970's
Hayward Station				
U. S. Cars	2	12	19	40
Foreign Cars		5	8	14
Total	2	17	27	54
North Berkeley Station				
U. S. Cars	1	13	19	35
Foreign Cars		6	10	16
Total	1	19	29	51

FIGURE 9

HOURLY PARKING LOT OCCUPANCY - NORTH BERKELEY STATION

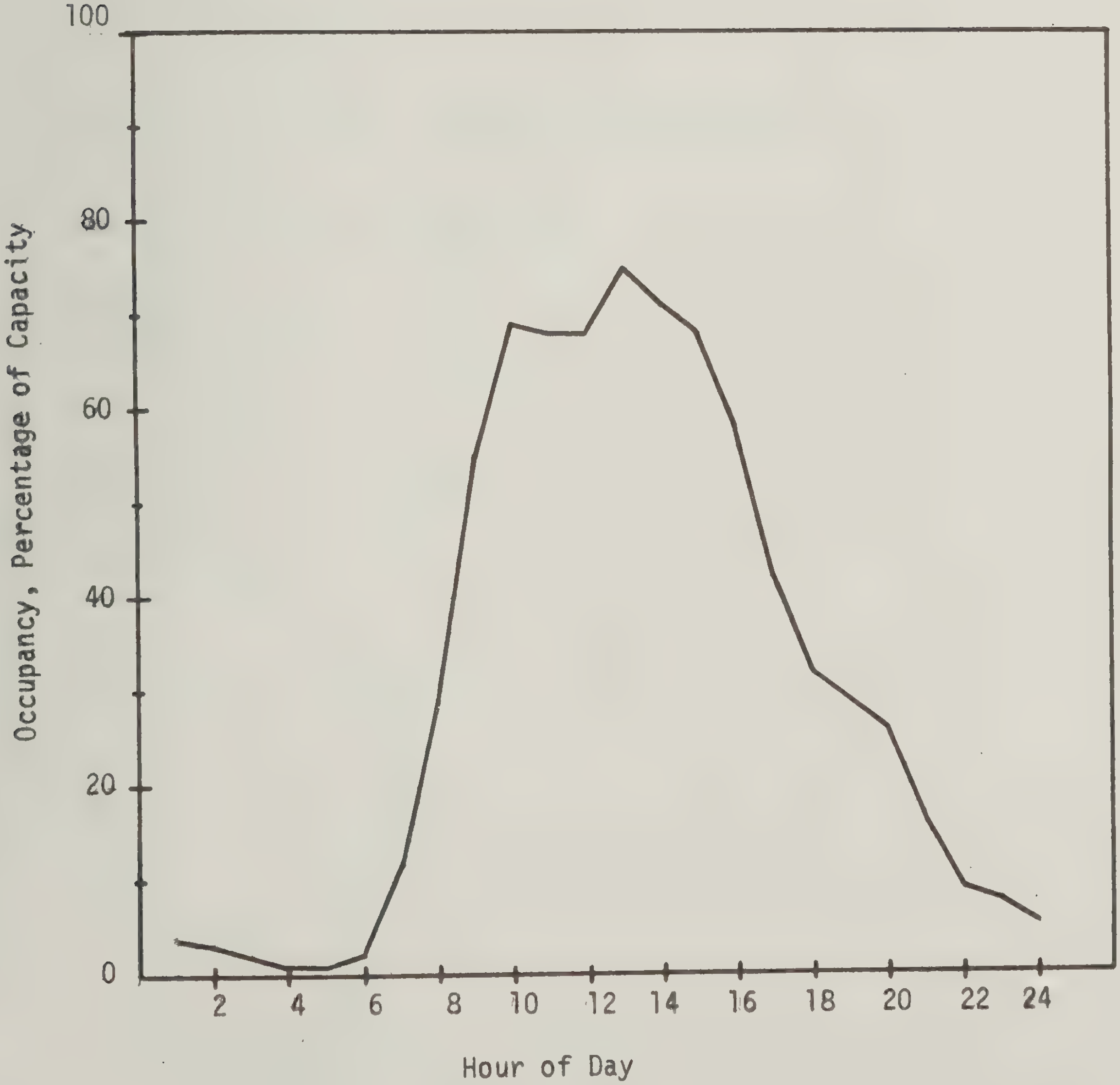
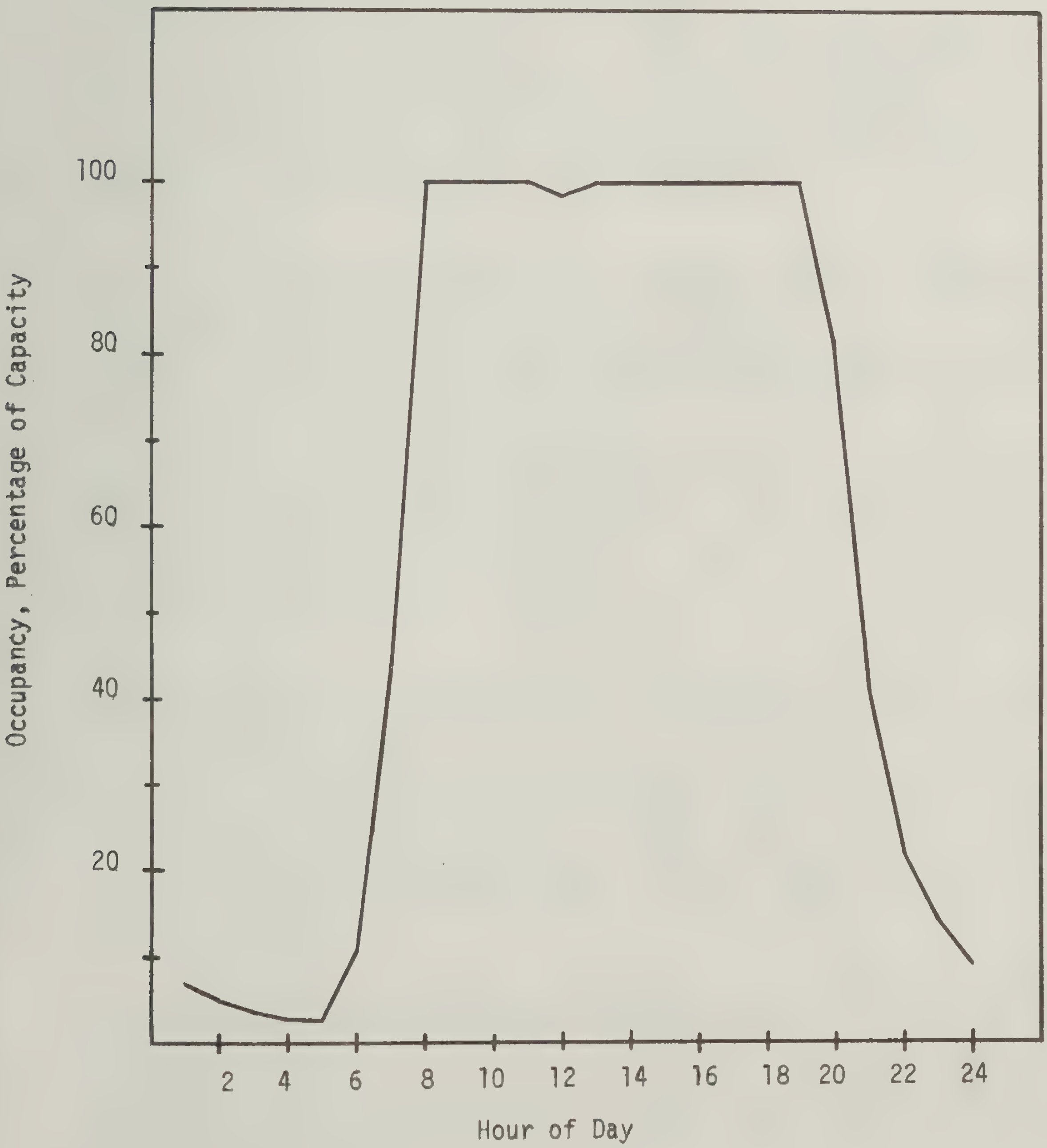


FIGURE 10

HOURLY PARKING LOT OCCUPANCY - HAYWARD STATION



Increasing occupancy of the parking facilities was generally attained on a segment-by-segment basis, with the segments closest to the station entrance maintaining the greatest occupancy levels. In either of the two study sites, each parking lot segment possesses separate access ways, which appears to be consistent with observations that traffic congestion did not increase appreciably with increasing parking lot occupancy.

Significance of BART-Induced Street Traffic

Observation of vehicle traffic in the vicinity of the stations indicated that, during the study period investigated, a relatively small percentage of the local vehicle travel is related to BART. This observation is substantiated in Table 9 with a comparison of the BART station parking lot traffic counts with typical traffic volumes of major adjacent and nearby arterials.

In the vicinity of the Hayward Station, the most heavily traveled arterial is A Street, which is one block north of the edge of the station parking lot (Figure 4). Orthogonal to A Street, Grand is the most heavily traveled. Table 9 shows that the magnitude of incoming and outgoing traffic volume at the Hayward Station parking lot is 28 percent of the total traffic volume on Grand and A Street during the morning heavy traffic period, and 18 percent of the Grand and A Street traffic activity during the afternoon heavy traffic period. These percentages are upper limit (local traffic counts on the less traveled streets were not done in the analysis) estimates of the proportion of local traffic which is BART-related, and provide an indication of the significance of BART-induced traffic in the station locality.

In the vicinity of the North Berkeley Station, the most heavily traveled arterial is Sacramento Street, which is adjacent to the east edge of the station parking lot (Figure 2). Orthogonal to Sacramento Street, Delaware Street is the most heavily traveled road. Table 9 shows that the magnitude of incoming and outgoing traffic volume at the North Berkeley parking lot is 22 percent of the total traffic volume on Sacramento and Delaware Streets during the morning heavy traffic period, and 14 percent of the Sacramento and Delaware Street traffic activity during the afternoon heavy traffic period.

Near each of the BART stations, the proportion of street traffic which is BART-related varies appreciably during the heavy traffic hours. At Hayward, early morning (6-7 a.m.) BART-related traffic is estimated to account for almost half of the traffic on streets near the station, and at North Berkeley, 42 percent of all traffic is BART-related for the 6 to 7 a.m. period. The proportion of street traffic which is BART-induced diminishes steadily with the morning hours, dropping to less than one-fifth by the 8 to 9 a.m. period. During the afternoon heavy traffic period, the trend of the morning is reversed, with the proportion of BART-related traffic increasing steadily into the early evening hours until approximately one-fourth of all street traffic near the station is bound for, or departing from, the parking lot.

TABLE 9
SIGNIFICANCE OF BART-RELATED TRAFFIC IN THE VICINITY OF THE HAYWARD AND NORTH BERKELEY STATIONS

BART Station	Hour of Day	Typical Arterial Traffic Volume (2 Major Traffic Arterials)*	Incoming and Outgoing Traffic Volume to BART Parking Lot	Percentage of Arterial Traffic Which is BART Related**
Hayward	6-7 am	739	342	47%
	7-8 am	1869	604	33%
	8-9 am	1874	307	17%
	4-5 pm	2891	260	9%
	5-6 pm	2717	358	13%
	6-7 pm	2100	648	31%
North Berkeley	6-7 am	317	132	42%
	7-8 am	1183	260	22%
	8-9 am	1557	289	19%
	4-5 pm	1920	220	11%
	5-6 pm	2237	262	12%
	6-7 pm	1229	292	24%

Source: Traffic Division of City of Hayward, Traffic Engineering Division of City of Berkeley.

* The most significant thoroughfares (in each direction) carrying traffic through the vicinity and to BART. At Hayward these thoroughfares are A Street and Grand, while at North Berkeley, these are Sacramento and Delaware Street.

** It is assumed that all BART-related traffic travels on two orthogonal major arterials near the station. This figure provides an indication of the proportion of local traffic which may be BART-related. The estimate is undoubtedly high, since total traffic counts are not reflected solely by volumes measured for the two arterials incorporated in the assessment.

The data indicate that BART-induced traffic would tend to affect the local air quality surrounding the stations to the greatest extent during the morning heavy traffic hours. During these hours, as much as one-fourth of the traffic on arterials in the station vicinity is either incoming or outgoing vehicles from the BART parking lot. The activity levels of BART-induced traffic on roads surrounding the station has special implication for air quality measured at the control sites. The background levels of CO generated by the local BART-induced traffic around the station and at the study control sites must be considered in the assessment of the state of the air quality environment before BART was installed.

Observations of Traffic Behavior

It is evident that the magnitude of motor vehicle emissions arising in and near the BART stations will be influenced greatly by the number of vehicles polluting the air. Monitoring of traffic volumes to quantify motor vehicle activity at the BART parking lots is an important element in the characterization of air quality impact origins. Another potentially important variable influencing the quality and magnitude of the impact origins (CO source emissions) concerns the operating mode of the motor vehicle. There are four distinct and probable driving modes associated with the motor vehicle behavior at the BART facilities:

Mode Number 1. Enter and park

Mode Number 2. Enter and stop, start and exit

Mode Number 3. Enter and stop/idle and exit

Mode Number 4. Cold start and exit

Vehicular emissions of CO may differ substantially between these operating modes. In addition, emissions may vary greatly for any given mode, depending on its exact specification. Any attempt to formally assess a specification of the various modes prevalent in the parking facilities, the traffic counts associated with these driving modes, or the corresponding emission factors of a given mode, is beyond the scope of this study. However, in an attempt to provide broad general insights into this very complex area, the air quality monitoring team conducted casual observations of motor vehicle behavior at each of the BART parking facilities. The results of these observations are related in the following discussion.

The predominant traffic pattern at either of the two stations in the morning heavy traffic period was Mode Number 1, while in the afternoon heavy traffic hours, traffic movement by Mode Number 4 was more frequently observed. At the North Berkeley Station, a greater proportion of vehicles exhibited the pattern of the second and third modes, in which the vehicle entered, stopped, and exited the lot ("kiss and ride"). Observations of the vehicles in these modes revealed that standing observed idle times of buses varied from 10 seconds to 2 minutes, and from 10 to 30 seconds for automobiles. The average idle time for a bus was estimated to be approximately 45 seconds, and for a car, it was about 15 seconds. Occasionally, a bus or car would stand idle for an exceptionally long time, but this generally did not occur more than twice during a single heavy traffic period. However, it was common to see buses stopped with the engine off for periods in excess of 10 minutes, and automobiles stopped with the engine off for 30 minutes.

Perhaps the most important observation by the monitoring teams was the observation that traffic congestion, at either of the two BART parking facilities, was non-existent. During the heavy traffic periods, including the hours of full or maximum occupancy, traffic was observed to move continuously, purposefully, and without the normal interferences associated with traffic congestion. Congestion of arterials in the vicinity of both stations was also observed to be non-existent. At North Berkeley, traffic at the intersection of Sacramento and Delaware, a main junction for BART-induced traffic flow, has been so light that the City is presently considering the removal of the traffic light there (Berkeley Public Works Department, 1975). The implication of the presence of minimal traffic congestion at and around the BART stations may be considerable in terms of the character of the various driving modes identified above, and subsequently, in terms of the expected CO emissions.

Modes Numbers 1, 2, 3 and 4 above would all be significantly affected by the extent of traffic congestion. The total number of stops, and the duration of the travel through the parking lot, are proportional to traffic congestion, as are emissions of CO from the vehicles. In the morning heavy traffic periods, when the majority of the vehicle traffic is incoming, the pattern of Mode Number 1 would perhaps be most affected by congestion, since the duration of the travel required to locate an optimal parking space would probably be increased greatly with congestion in the parking lanes. During the heavy traffic of the afternoon, when most of the vehicles are leaving the parking lots after a cold start, the pattern of Mode Number 4 is perhaps the most affected by congestion, due to increased travel necessary to exit the parking lanes when congested. However, since congestion is minimal in both parking lots, the impacts of Modes Numbers 1, 2, and 3 are minimized relative to Mode Number 4. This is because the

emissions due to actual travel duration and stop-and-go type driving patterns are decreased with decreasing congestion, while the cold-start emissions from parked vehicles remain the same regardless of congestion levels. While the quantification of the role which traffic congestion may exercise in the overall level of CO emissions arising from the various vehicle modal patterns was not possible, it is clear that traffic emissions of CO are significantly reduced when traffic congestion is minimized, and that suitable design of parking facilities may be instrumental to the attainment of this benefit.

Noxious Odors

Of the major emissions which make up diesel and gasoline engine exhaust, the hydrocarbons and aldehydes are most responsible for odor. The hydrocarbons which are found in motor vehicle exhaust are methane, ethane, propane, C_5 to C_7 paraffins, acetylene, ethylene, propylene, butanes, C_5^+ olefins, benzene, toluene, and C_8^+ aromatics and paraffins (Taliaferro, 1974). Both gasoline and diesel engines exhaust materials containing roughly equal amounts of unburned fuel, and both types emit hydrocarbons in the boiling range of their fuels. However, diesel engine exhaust is much more odoriferous than gasoline engine exhaust; consequently, most of the efforts to identify odor-causing vehicle emissions have involved the study of diesel engine exhaust.

The C_8^+ hydrocarbon emissions appear to be most responsible for odors characteristic of diesel engine exhaust. The individual species of C_8^+ hydrocarbons contributing to diesel exhaust odors are very numerous and variable in their occurrence. Generally, 80 percent of the hydrocarbons in diesel engine exhaust is composed of paraffins having no odor. About 17 percent is composed of aromatic species having a characteristic oily-kerosene odor, while 3 percent is composed of oxygenate species which give a characteristic smoke-burnt odor. The oily-kerosene odor is associated with the aromatics of the unburned fuel, and the smoky-burnt odors come from partial combustion of the paraffin and aromatic fuel components. It has been estimated that the oily-kerosene aromatics, about 200 distinctly different chemical species, have a concentration of about 20 ppm in the exhaust. The smoke-burnt oxygenates, which are made up of about 2,000 species, have a concentration of about 5 ppm in diesel exhaust (Levins, 1974).

The health effects of the odor-producing vehicle emissions on humans are negligible in the range of ambient concentrations which are expected in the immediate vicinity of idling buses and other motor vehicles. Of the odor-causing chemical species emitted, ethylene, propylene, and acetylene are members of the aliphatic group which exhibits anesthetic properties, but no biological effects have ever been known to occur from these species under 500 ppm as they are so rapidly metabolized (Summer, 1971). The aromatic exhaust gases, benzene, toluene and certain other aromatic hydrocarbons are more biochemically active. Their vapors can be irritating to mucous membranes, and at high concentrations (over 100 ppm), there is a pronounced effect on the central nervous system. However, these aromatics are known to have no effect below 25 ppm. The concentration of total aromatics in diesel exhaust gas is about 20 ppm, but it should be noted that this is a source concentration, not an ambient concentration.

While some unsaturated aldehydes contribute to a portion of the exhaust odor complex, the most abundant exhaust aldehydes do not appear to contribute significantly (Levins, 1974). The most important effect of some of the lower molecular weight aldehydes is the irritation effect on the skin, eyes, and upper respiratory tract. Although aldehyde concentration has been known to correlate with the intensity of eye irritation resulting from naturally and chemically produced smogs, the effects attributable to aldehyde inhalation have been produced only by concentrations far above the levels found in ambient air (Summer, 1971).

During the two-day study of carbon monoxide concentrations and observation of motor vehicle traffic at the two BART stations, the strongest occurrence of odor due to motor vehicle exhaust occurred at the Hayward Station, in the period from 7 to 8 a.m. At this time there were only very subtle air currents in the immediate area of the station entrance, which also happened to be the bus and car ride passenger waiting area. The stillness of the air, combined with the density of motor vehicle activity associated with that time of the morning, provided for a buildup of residual exhaust emissions in the area. During this time, one could stand in the passenger ride waiting area and "smell a bus" without seeing one. This residual effect also occurred in the turnstile entrance area, just inside the station entrance, where the CO monitoring instrumentation was located. Gasoline engine exhaust was much less noticeable during this period; one would generally have to stand much closer to an idling car than to an idling bus to smell it.

In the afternoon sampling period at Hayward, there was a steady wind from the southwest which did not provide for a buildup of residual exhaust odors. Also, odors from buses and other automobiles were not as noticeable as the afternoon wind seemed to diffuse the exhaust rapidly. This diffusion probably occurred over the parking lot, to the northeast of the station, and in the direction of subject monitoring point "M". As bag samples were taken at point "M", it was noted that there was no trace of any type of motor vehicle exhaust odor, except for the occassional and brief smell of a passing motor vehicle on B Street.

During this two-day period, the most notable odor of gasoline engine exhaust occurred at the time when bag samples were being taken at control point "Y" on B Street at Hayward, during the afternoon rush period. At this location, the odor seemed to be of a residual nature as there was a steady flow of automobile traffic, with no single engine being responsible for the total intensity of the odor. Also, the exhaust odor intensity, as well as the level of CO, stayed relatively high throughout most of the dusk period.

Diesel and gasoline exhaust odors in and around the North Berkeley BART station were substantially less noticeable than at Hayward. In the morning sampling period at North Berkeley, there was only a very slight breeze from the east. With the Sacramento Street section of the parking lot being the most active and the car and bus ride activity located to the east of the station entrance, there would have appeared to have existed a very high potential for a residual odor buildup. However, an accumulation of residual exhaust odor did not occur, due quite likely to the relatively low density of recently passing and nearby idling motor vehicles. The only odors sensed at the station entrance and at the car and bus ride waiting area were from individual vehicles, and such occurrences were short-lived.

In the afternoon sampling period at North Berkeley, a wind had developed from the west, and individual odor occurrences were extremely short-lived and generally limited to only the car and bus ride waiting area. All odoriferous exhaust gases seemed to be rapidly diffused by air movement.

X. CONCLUSIONS AND IMPLICATIONS

This section provides a development of conclusions synthesized from findings presented in the previous section. The conclusions are developed to be responsive to the principal objectives of the study. Accordingly, the first subsection which follows provides a development of conclusions relating to the nature and significance of the impact of BART-induced motor vehicle traffic on ambient air quality in the immediate vicinity of the Hayward and North Berkeley BART Stations; and the second subsection contains the development of conclusions involving the relationship between various impact determinants (such as attributes of the Hayward and North Berkeley BART Stations and the meteorology at the BART environments) and the air quality in the immediate area.

IMPACT OF BART ON LOCAL AIR QUALITY

The study findings support the following general conclusions:

- The impact of BART-induced motor vehicle traffic on ambient air quality in the vicinity of the BART stations is relatively minor. Air quality at the BART station and surrounding vicinity is not appreciably different than would have been expected had BART not been installed.

- The most significant impact which BART exerts on local air quality occurs during the heavy traffic periods of the morning and afternoon. Because stable atmospheric conditions conducive to pollutant buildup are more frequent in the morning hours, the impact of BART-induced traffic emissions is generally greater in the morning hours. The impact of BART-related activity on local air quality during other hours of the day is insignificant.

- The greatest impact on local air quality due to BART activity occurs at the station parking lot. During the peak traffic periods, hourly ambient concentrations of CO in the parking lot may be a few parts per million greater than the level which would have occurred under the No-BART baseline reference. In the neighborhood surrounding the stations, hourly ambient CO levels are only slightly greater than would have existed had BART not been installed. At either of these two locations, the actual magnitude of the incremental change in air quality due to BART is not appreciable. The resulting peak ambient concentrations of CO are relatively low and are well within the allowable ceiling levels specified by the National Ambient Air Quality Standards.

The above conclusions were developed by a comparison between the baseline air quality associated with the No-BART alternative and the actual air quality corresponding to the present state of the environment. Before such a comparison could be carried out, it was necessary to synthesize the findings of Chapter IX to determine: 1) the character of the existing local air quality in the BART station parking lots and surrounding neighborhood, and 2) the character of the local air quality in the vicinity of the BART stations had BART not been installed.

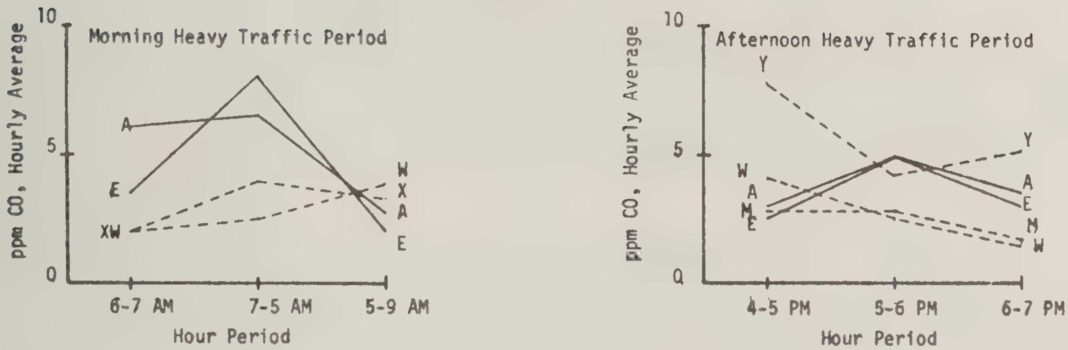
The characterization of local CO levels corresponding to the No-BART condition was represented by CO levels measured at the selected control sites, with suitable adjustment to correct for CO origins which were BART-related. Control sites were located in positions where prevailing winds would not permit influences by CO origins at the BART station, but it was not possible to locate control sites independent of the influences of BART-induced street traffic. In adjusting for the latter effect, it was presumed that the contribution of BART-related street traffic to levels of CO at the control sites was equivalent to the contribution of BART to overall levels of traffic volume on the arterials around the station. Table 9 summarizes the relative contribution of BART-induced street traffic to overall traffic on arterials around the station for the heavier traffic periods of the day. It should be noted that these estimates are upper limit estimates of the proportion of traffic which is BART-related, since local traffic volume on the less traveled streets in the vicinity was not included in the analysis. The presumption that CO levels at the control sites increase in proportion to the number of vehicles on nearby streets is applied in Figure 11 to yield estimates of the air quality of the environment before BART was installed. The adjustment is also applied to measurements reported at the impact sites, since these are also affected by BART-induced street traffic. The profiles of Figure 11, plus the findings associated with measurements taken at the impact sites, were examined in deriving the general conclusions stated at the beginning of this section. Specific conclusions and findings relating to these general conclusions are summarized below:

- Based on observations of BART-related traffic activity versus other traffic activity in the vicinity of the BART stations, plus careful consideration of wind direction, it is concluded that monitoring data at the control sites, with some adjustment for BART-related street traffic, is representative of CO levels which would exist at the same site if BART had not been installed.

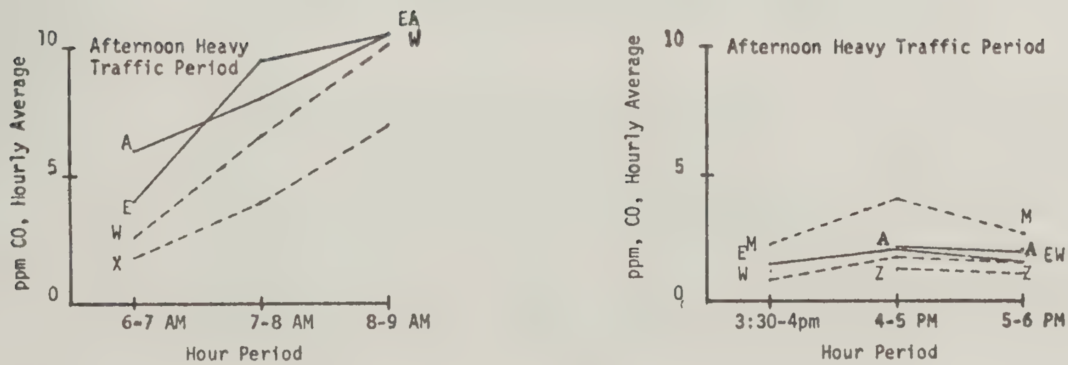
FIGURE 11

CHARACTERIZATION OF AIR QUALITY FOR CURRENT STATUS AND NO-BART ALTERNATIVE

HAYWARD STATION



NORTH BERKELEY STATION



LEGEND OF SITES:

E - Station Entrance
A - Parking Lot "Walking" Bag Sample
W,X,Y,X - Control Sites, Adjusted to No-Bart Environment
M Impact Sites, Adjusted to No-Bart Environment

- Levels of CO monitored at sites downwind (impact sites) of the BART stations were not found to contrast significantly (except when the site was located close to another pollution source--Sacramento Street) with levels of CO measured at control sites. This provides supportive evidence that emissions of CO at the BART station produce minimal impact on the air quality in the surrounding area.

- Applying the findings associated with air monitoring of control sites and traffic monitoring of vehicle activity, it may be concluded that ambient levels of CO in the former communities (pre-BART environment) located at the current Hayward and Berkeley BART parking facilities were relatively non-homogeneous. Ambient air monitoring results suggest that local sources of CO emissions vary significantly within the small peripheral area surrounding the two BART facilities in the study.

- Variations in CO concentrations in the vicinity of the BART stations are related to CO source activity in the immediate area of the sampling site. The highest CO levels are consistently found at the sites near the more heavily traveled streets.

- Hourly ground level concentrations of CO in the vicinity of the BART stations are representative of "outdoor walking exposures" and are therefore appreciably higher than the average exposure an individual would experience on an hourly basis. Hourly levels of CO reported by District Monitoring Stations in the nearby areas are intended to reflect representative hourly exposures; therefore, these values contrast significantly with the short-term CO exposure levels measured in the study.

- BART patrons entering the station from the parking lot may be subjected at times to short-term exposures of CO which substantially exceed the expectant level of pedestrian exposure for baseline levels in the adjacent neighborhoods. This is due to inconsistent patterns of traffic activity in the parking lot, which during brief periods of congestion cause high levels of CO emissions and subsequently, high short-term localized CO concentrations.

ATTRIBUTES AFFECTING IMPACT

The most significant attributes which affect air quality at a given site in the vicinity of the BART stations were identified as: 1) the activity (volume of traffic) of the impact origin, 2) the (stop, go, idling) behavior of the impact origin, 3) the proximity of the site to the impact origin, and 4) wind direction and strength. Due to the constraints of the study program, it was not possible to quantify the relationship of these impact determinants with local air quality. However, the study results do permit a broad overview of impact determinants, providing support for the following conclusions:

Wind Strength:

- The most significant impact determinant affecting local air quality in the vicinity of BART stations is wind strength. During periods of unusually stable atmospheric conditions, ambient concentrations of CO will build up steadily over the station parking lot and throughout the neighborhood. This phenomenon is not peculiar to areas at BART stations, as CO levels at other study sites (control sites) removed from the origin of BART activity were also observed to increase steadily during periods of stable atmospheric conditions. The effect of wind movement was demonstrated dramatically during the study when CO levels in the stable atmosphere of the North Berkeley Station exceeded values recorded in the less stable atmosphere of the Hayward Station, despite the presence of appreciably higher source emissions generated at the Hayward Station.

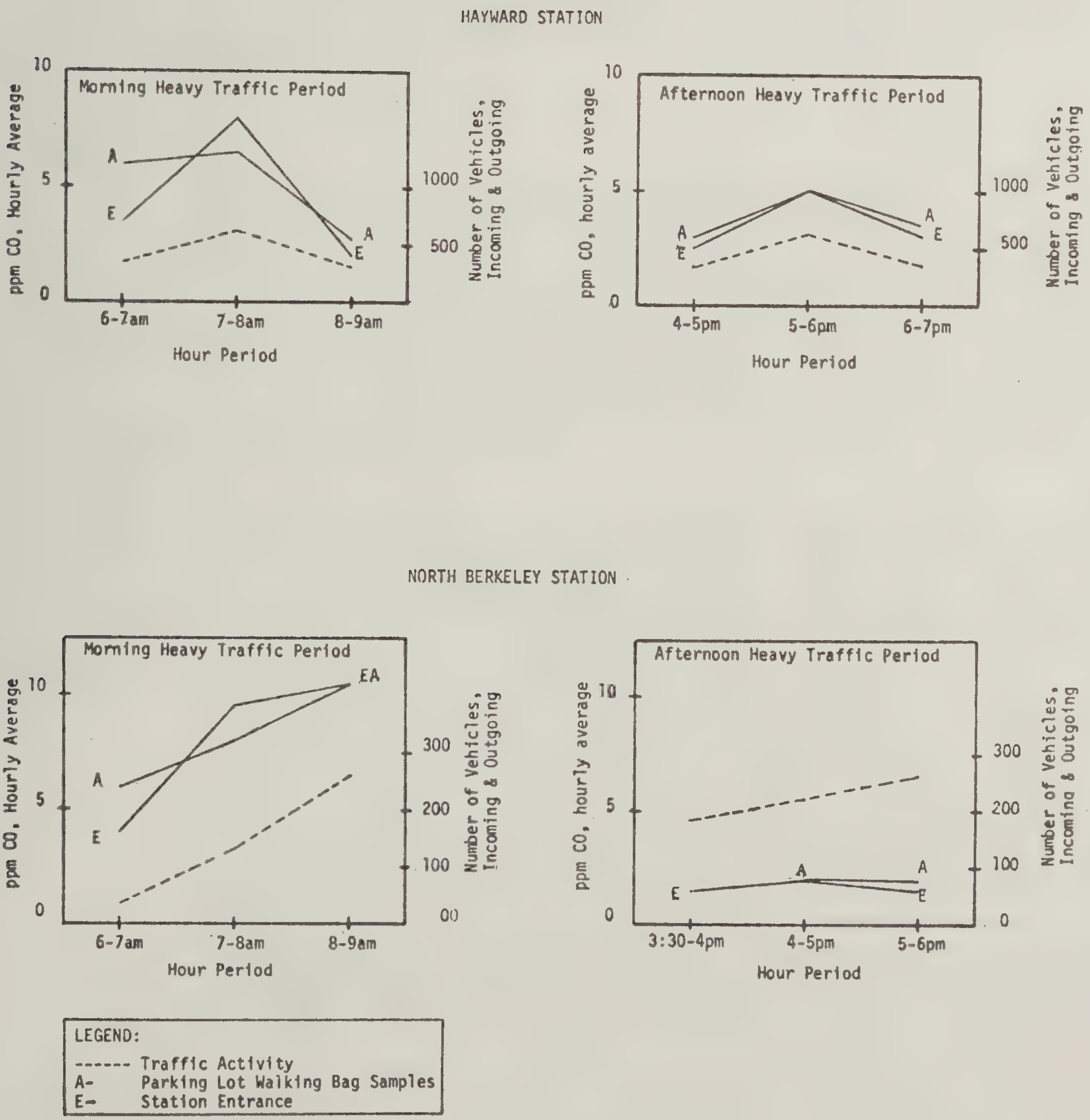
- The atmospheric diffusion rates associated with typical Bay Area atmospheric conditions are apparently sufficient to prevent ambient CO buildup in the vicinity of the BART stations. While ambient concentrations of CO at the stations may be expected to increase during the heavy traffic periods of the morning and afternoon, the peak levels which occur are generally short term, and relatively low in magnitude.

Traffic Activity:

- The level of BART-related traffic activity at the BART stations is an important variable to ambient CO levels at the station. For a given wind strength and ambient site, a certain level of traffic activity is needed to generate a given ambient level of CO. This apparent relationship is shown in Figure 12, as peak levels of CO in the parking lot occur coincidentally with peak levels of parking lot traffic activity. The relationship is mitigated by other intervening factors (such as the influence of winds), as exemplified by the difference in the magnitude of

FIGURE 12

RELATIONSHIP OF TRAFFIC ACTIVITY AND AIR QUALITY



CO peaks which occur for a given level of traffic activity from morning to afternoon.

- Air quality in the neighborhood surrounding the BART station is directly related to the level of BART-induced traffic activity on the streets providing accessibility for the BART stations. The impact of BART-related street traffic on local air quality is most pronounced in the heavy morning traffic hours, when the portion of all street traffic in the vicinity of the station bound for or departing from the BART station is greatest (see Table 9).

Traffic Behavior:

- The nature of traffic behavior in the BART parking lot is an important variable influencing the magnitude of CO emission. Vehicular emissions of CO differ substantially between the various driver patterns associated with motor vehicle behavior at the BART facilities. Any attempt to formally assess a specification of the various modes prevalent in the parking facilities, the traffic counts associated with these driving modes, or the corresponding emission factors of a given mode, was beyond the scope of this study.

- Behavior of traffic in the BART parking lots may differ substantially between different stations; consequently, emissions of CO exhausting from vehicles at the stations will also contrast substantially. At the North Berkeley Station parking lot, traffic activity includes an appreciable portion of through traffic ("kiss and ride") during the morning heavy traffic periods, while at Hayward, morning traffic activity consisted almost entirely of vehicles which would remain parked at the lot. This contrast between traffic behavior at the two stations may give rise to greater proportions of idling time in the North Berkeley parking lot, and emissions of CO there may be significantly greater than at Hayward for a given level of traffic volume. However, in the afternoon heavy traffic period, cold starts from vehicles in the larger Hayward parking lot would be expected to give rise to a magnitude of CO emissions greater than would be generated for the same period at the North Berkeley Station.

- Determinants of traffic behavior at the BART parking facilities are: parking lot occupancy, level of traffic activity, parking lot configuration, the benefit and services associated with travel on BART at the specific station, and the socioeconomic mix of the patrons. Traffic congestion, caused by combinations of these determinants, affects traffic behavior dramatically. The frequency of vehicle stops, and the duration of travel through the parking lot, are proportional to the level of traffic congestion, as are emissions of CO from the vehicles.

- Traffic congestion, at either of the two BART parking facilities, and on arterials in the station vicinity, was generally non-existent. Traffic congestion does not increase appreciably with increasing lot occupancy. The minimal extent of congestion is apparently attributable to the parking lot design, which features separate access ways to the multiple lot segments, spacious parking lanes, and a central station entrance. Hence, it may be concluded that suitable design of the BART parking facilities has been instrumental in mitigating the potential impact of BART-induced traffic on local air quality at the stations, and in maintaining local air quality in compliance with federal ambient air quality standards.

Proximity of Site to Impact Origin:

- CO levels in the vicinity of the BART stations are consistently higher at the sites located at or close to the greatest traffic activity. Consequently, the highest levels of CO are typically found in the parking lot near the entrance to the BART station. The highest short-term concentrations of CO may occur at any site close to traffic congestion, and are most frequently associated with the traffic near the BART entrance. Levels of CO observed at sites in the area surrounding the BART station are generally highest at the sites near a major traffic arterial.

- Street level ambient concentrations of CO diminish rapidly with distance from the impact origin. Measurements support the conclusion that emissions of CO at the BART station exert relatively minor impact on CO levels in the adjacent neighborhood downwind of the BART parking lot.

TRANSFERABILITY OF FINDINGS

The assessment of the probable impact which any given impact origin may induce on the surrounding air quality is dependent on: 1) an identification of significant impact determinants, 2) an accurate characterization of these determinants, and 3) an understanding of the relationship between the impact determinant and the probable resultant impact. The implications of Hayward and North Berkeley Station study findings for other BART stations, and for other transit systems, depend mainly on the degree to which these findings will permit the execution of the assessment scheme above.

The study has revealed that several determinants are involved in the impact which BART exerts on local air quality. It has not been possible within the scope of the present study to quantify the specific relationship between these impact determinants and their resultant impact. It is clear, therefore, that the findings of the present study will have far greater implication for transit system station operations which bear appreciable similarity to the North Berkeley and Hayward Station operations than for other systems possessing contrasting impact determinants, or contrasting determinant characteristics.

In the present study, two BART stations were selected for study, with the presumption that the selected stations could be chosen to be representative of the existing range of BART stations with respect to intensity of impact origins induced by station operation. The Hayward Station was selected to represent BART sites which induce heavy motor vehicle traffic, and the North Berkeley Station was chosen to reflect BART sites which induce light volumes of motor vehicle traffic. It was presumed that the assessment of impact which each of these stations would exert on local air quality would be directly related to other BART stations. However, the validity of this assumption can only be determined after the various impact determinants associated with each of the BART stations can be characterized and the resultant impact assessed. This evaluation may or may not be possible within the context of the insights offered from the present study, depending on the nature of the determinants, and their similarity to variables examined in the current study of the two BART stations.

IMPLICATIONS OF IMPACT DETERMINANTS

The study has identified three major categories of impact determinants related to the influence of BART stations on air quality: 1) wind strength, 2) traffic activity, and 3) traffic behavior. The insights of the study in relating effects associated with these determinants were discussed in the previous section. The implications of these insights, for the planning of transit systems or for other BART stations, are discussed in the following subsections. The first subsection contains a discussion of implications of the study findings relating to the influence of wind strength, the second

presents implications relating to study insights on traffic activity, and the final subsection provides possible implications indicated by study findings on traffic behavior.

Wind Strength:

- The assessment of the impact which existing or proposed transit stations exert on local air quality depends substantially on meteorological characteristics of the site area. The occurrence of stable atmospheric conditions for extended periods permits the steady buildup of pollutant levels when the activity of origins is sustained. The probable extent and frequency of stable conditions must be determined before adverse air quality impacts can be accurately assessed.

- An important constraint in the design of future transit system stations is the meteorology associated with the installation site. Based on the study findings, it appears that relatively little air movement is necessary to provide adequate natural removal mechanisms for pollutants generated at stations with relatively high levels of traffic activity (Hayward and North Berkeley). Transit station design criteria should insure that potential pollution from motor vehicles at the station will be naturally diffused under the most unfavorable meteorological conditions probable.

Traffic Activity:

- The formalized assessment of probable impact of traffic activity at transit stations on local air quality depends on the quantification of the relationship between these variables. The study findings are unable to provide quantified guidelines for air quality impact assessment, and therefore carry implications primarily for assessments of transit systems with levels of traffic activity similar to those examined in this study (1,600 to 3,000 vehicle movements per day). Based on extrapolation of study findings, it is clear that, with proper design of the parking facility, relatively high levels of traffic activity (3,000 vehicle movements at the Hayward Station) may be sustained at transit parking lots without incurring appreciable impact on air quality in the area. The ability of the transit station to absorb heavy patronage levels without incurring significant additional effects on local air quality carries important implications for the economic and physical design aspects of proposed transit systems.

- The study results show that the impact of transit station operations on air quality in the adjacent neighborhood is due more to transit-induced street traffic than to traffic activity at parking lots. Assessment of probable impact of proposed transit station operations on local air quality should consider the relative increases in local motor vehicle traffic induced on streets in the surrounding neighborhood.

Traffic Behavior:

- Traffic behavior is probably the most significant impact determinant constraining the physical design of the transit station. Various transit station attributes must be considered in targeting the design of the station for specific traffic behavior. These attributes include parking lot occupancy, level of traffic activity and parking lot configuration.

- The observations in this study suggest that the designs of the North Berkeley and Hayward Station parking lots were successful in regard to their impacts on local air quality. The small amount of traffic congestion at these stations, partly a result of their designs, undoubtedly had much to do with the relatively low levels of CO observed there.

ISSUES FOR CONTINUED STUDY

The study has established findings which are responsive to the study objectives, and has raised other significant issues in the process. These issues involve: 1) the relationship between specific impact determinants and air quality impact, and 2) the communities' perception of BART influence on air quality and their subsequent response.

Impact Determinant/Impact Relationship

Within the limited scope of the study, the specific relationship between the various individual impact determinants and the resulting impacts could not be quantitatively assessed. Therefore, implications of the study findings for transit system operations contrasting significantly with the case study examples are limited. For example, consider the possibility that operation at one of the BART stations is characterized by heavy traffic congestion, traffic activity to parking lot capacity ratios several times that observed in the current study, and prolonged stable atmospheric conditions. It is conceivable that the impact

of each of these determinants could cumulatively result in ambient air quality which is in violation of federal air standards. The ability to predict the actual impact of such conditions (not representative of any of the BART stations) is beyond the scope of understanding provided by the current study. To expand the meaning of the study to a wider range of circumstances, additional effort must be undertaken to study situations reflecting contrasting determinant values, so that cause-effect relationships may be more definitively assessed. The additional study should be focused on the more significant determinants affecting local air quality, namely, meteorology, traffic activity, and traffic behavior.

In expanding the scope of the study to include definitive assessment of impact cause-effect relationships, it is anticipated that an extensive monitoring program would be employed to characterize air quality impact under varying conditions for each determinant. Traffic activity levels at the selected transit station sites should reflect a wide range of values as determined by a survey of different transit system operations. Traffic behavior studies should reflect a wide distribution of vehicle driving modes. Situations where traffic congestion is light, medium, or heavy should be represented. Traffic behavior created by various parking lot configurations should also be considered in the study. The meteorological parameters should be closely monitored to insure that study results may be correlated with a wide range of wind strengths.

The expanded study objectives may or may not be accomplished by studying BART facilities alone. Distinctions which other transit systems may have relative to BART should be identified, and an evaluation should be performed to determine if these distinctions are related to impact determinants not represented by BART. In this manner, it may be determined that other transit system operations should be incorporated in the proposed monitoring program as well.

The study of air quality cause-effect relationships for complex sources such as parking lots has received limited attention in the past, and presently there are no standard methods for evaluating these sources. However, the Environmental Protection Agency has recognized the necessity of formulating a complex source evaluation methodology and is committed to further study on this issue. Hence, the expansion of the current study program to a wider scope, with the intent of formulating relationships between complex source attributes and local air quality impacts, is timely in terms of present clean air objectives. In a sense, the major value of the additional research suggested here is probably more related to general application than to the BART Impact Study Program.

Public Perception and Response

The current study has provided an evaluation of the physical impact which BART stations operations exert on air quality within the vicinity of the station. An additional related issue concerns the impact which is perceived by the community. Both the real impact and the perceived impacts cause responses. The physical air quality impact induces predictable biological response from plant and animal life. The perceived air quality impacts also induce responses, but the actions characterizing these responses are dependent on social and economic factors, and are therefore difficult to predict.

The study has revealed that BART station operations induce minimal impact on local air quality. The magnitude of the increases in local pollutant levels caused by BART station operations will produce no measurable biological response by plant or animal life. However, the BART local air quality impacts which are perceived by the local and regional community are presently unknown. As part of the survey planned for Phase II of the project, to study responses to the entire array of environmental impact, the following questions should be addressed:

- Public impressions of air quality changes caused by BART stations.

- Effects which these perceived changes have induced in the community.

- Related attitudes or determinants of perceptions and responses, such as: 1) respondent awareness of BART station operations, 2) respondent attitudes with respect to rapid transit in general, 3) socioeconomic characteristics of survey respondents.

Because of the minor influence of BART operations on local air quality, it is anticipated that public perception and response with respect to the BART air quality impact issue will be rather undramatic.

XI. METHODOLOGY

AIR QUALITY MONITORING

Instrumentation

The concentration of carbon monoxide in the ambient air was measured using an Energetics Science Inc. Ecolyzer, Model 2600 (Figure 13). This is a compact and portable unit capable of functioning with either a battery pack or an AC line current. The detection principle of the Ecolyzer is electro-chemical; carbon monoxide is electro-oxidized at a catalytically active electrode (e.g., platinum) in an aqueous electrolyte according to the equation:

$$CO + H_2O \xrightarrow{\text{Catalyst}} CO_2 + 2H^+ + 2e$$

An electric current, measured upon the introduction of carbon monoxide sample to the detector,[1] is proportional to the partial pressure of carbon monoxide in the sample. The current generated is amplified and displayed on a panel milliampmeter in units of carbon monoxide concentration. The range of the meter is from 0 to 100 parts per million (ppm) with 100 divisions. To obtain an accurate and permanent record of the measured concentrations during the course of this project, an Esterline Angus (Model T171B) strip chart recorder was connected to the Ecolyzer. This procedure eliminated the necessity of having a person constantly stationed at the Ecolyzer to manually record the measured concentrations. The maximum error in the concentrations recorded is 2%, with 1% attributable to the Ecolyzer and 1% to the recorder. Although both instruments possess a dual battery/AC line current operational capability, it was decided to run both units on AC line current to eliminate any possibility of battery failure and/or early discharge.

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[1] There is an injection port located on the face of the instrument (see Figure 13). A built-in pump draws ambient air through the port into the Ecolyzer. Samples can also be introduced into the port from a polyethylene bag which contains air collected at locations away from the Ecolyzer. This method is known as "grab bag" sampling and permits the monitoring of several sites without moving the instrument. The first method is commonly referred to as "continuous sampling," where air in the immediate vicinity of the Ecolyzer is sampled.

FIGURE 13

CO MONITORING EQUIPMENT

Site Selection and Monitoring

The monitoring operation took place over a three-day period, February 25-27, 1975. On the first day, both the Hayward and North Berkeley Stations were visited to permit the monitoring personnel to familiarize themselves with the station area and surrounding neighborhood. In addition, the exact locations of the control and station monitoring sites were determined. The actual monitoring occurred on the 26th for Hayward and the 27th for North Berkeley. Each station and its corresponding control sites were monitored only during the peak morning and afternoon rush hours, since these periods generally reflect the time of greatest vehicular activity and hence the highest emissions of carbon monoxide. The peak morning traffic hours were defined as 0600-0900 hours for each station; however, it was anticipated that afternoon heavy traffic periods would be different for each station (due to differing residential character of neighborhoods). Afternoon traffic hours from 3 to 6 p.m. were selected for the monitoring period at North Berkeley, and hours from 4 to 7 p.m. were investigated at Hayward.

Two locations at each station site were monitored. One was near the ticket-operated turnstiles where the Ecolyzer was positioned and carbon monoxide monitored continuously. This location was chosen because all BART patrons pass through the turnstiles and thus are exposed to the CO concentrations present in the area. The second location is actually a grab bag sample of ambient air taken to be representative of the exposure of a BART patron walking from the parking area into the station. This "profile" route was selected so that it started within the parking area, went through the pickup and dropoff area in front of the station and ended at the turnstiles. The profile sample was considered to be representative of the "worst case" exposure since it was routed through the pickup and dropoff area.[1]

Four potential control sites were established north, south, east and west of each BART station. The control sites actually used during the monitoring were the ones upwind from the station and ones normal to the wind direction away from the station. This was done to minimize the effect of carbon monoxide generated from BART parking lots on concentrations recorded at the control sites (i.e., no control sites were chosen immediately downwind of BART stations).

[1] This is because both buses and automobiles are stopped with engines idling as they discharge and pick up people. For a given period of time, an idling engine produces more carbon monoxide than one under load in a moving vehicle.

In addition to the control and station sites, one other monitoring location was selected in the neighborhood immediately downwind from the BART stations to assess the maximum impact of CO emissions from BART-related traffic or CO concentrations on the adjacent neighborhood. This site was designated the "impact site."

The sampling procedure at the control and impact sites consisted of the technician gathering the sample to commence filling the "grab bag" approximately 15 feet prior to reaching the site, continuing the filling of the bag when at the site for approximately 20 seconds, and finishing the filling of the bag when walking away from the site (approximately another 15 feet).

During the periods of sampling, a profile was taken every 15 minutes and a control site was monitored simultaneously with the profile. Two control sites were always alternated in such a way that each control was monitored every one-half hour. A continuous observation of weather conditions was made throughout the sampling periods.

The monitoring personnel were additionally instructed to note the presence of any noxious odors in the station area. These odors are actually exhaust fumes from motor vehicles, and in particular, diesel-powered buses. No measurements of any odors were carried out.

Hayward

The Hayward BART station is located in an area characterized by a mixture of commercial and residential structures. Figure 4 shows the station, its associated parking lots and the surrounding neighborhood. Of the streets which are in the immediate vicinity of the station, Watkins, Atherton, A Street, Grand and C Street have mostly commercial activity; Montgomery, B Street and parts of Atherton and Grand are residential.

The corners of Watkins and B Streets, Watkins and C Streets, Grand and B Streets, and Montgomery and A Streets are controlled by traffic signals. There are stop signs on Montgomery at B Street, Atherton at B Street, C Street at Atherton, and Atherton at D Street. There are no four-way stops at any intersection close to the station.

Four potential control sites were selected and designated W, X, Y and Z (Figure 14). W and Y were established in residential areas. Site W was put on Montgomery Street approximately 150 feet north of the intersection of Montgomery and A Street. Observation of traffic flow on these streets revealed that Montgomery was very lightly traveled by vehicular traffic while the converse was true for A Street. The traffic on both these streets was rarely associated with BART station activity. Site Y was placed on B Street, about half a block west of the intersection of B Street and Grand, Although the area is totally residential, B Street and Grand were heavily

FIGURE 14

HAYWARD BART STATION - CO MONITORING SITES

LEGEND OF SITES:	
E	- Station Entrance
A	- Parking Lot "Walking" Bag Sample
M	- Impact Site (Downwind from BART Station)
W,X,Y,Z	- Control Sites

traveled all day, and much of the BART-associated traffic was observed to pass this intersection. Control sites X and Z were in commercial areas. Site Z was placed next to an industrial parking lot on D Street, between Atherton and Montgomery; site X was placed on Watkins, midway between the intersections of B Street and Watkins and C Street and Watkins. This section of Watkins had traffic observed to be seldom associated with station traffic.

The impact site (designated M) was at the corner of B and Atherton Streets.

The profile route (marked as "A" in Figure 14) started within the major parking lot east of the station, crossed the lot's major throughway and went along the traffic island separating the throughway and the street passing in front of the station (this island was a major waiting area for people and idling vehicles). The profile route then crossed the street at the crosswalk, went down the steps entering the station and over to the Ecolyzer.

The Ecolyzer was placed inside the entrance at the south end of the station. The entrance at the north end was not as heavily used and the bus and car activity on the north was not nearly as great as at the southern entrance.

The monitoring team arrived at the Hayward station at 0550 hours to set up the equipment. At this time there was already some bus and car activity and there were 100 parked cars in the lot.[1] A station attendant said that when the station opened at 0500, there were about half as many parked cars which were presumed to have been there overnight.

The sky was overcast and remained so throughout the morning. The air was generally very still, with a slight breeze from the east. It was therefore determined that the two control sites to be monitored would be W and X. Site X was upwind from the station and W was normal to the wind direction. Monitoring for the afternoon rush hours commenced at 1600 hours with the weather clear, sunny and a slight wind from the southwest. Because of this shift in wind direction from morning to afternoon, control site X was not minitored, as it was downwind from the station. Instead, control site Y on B Street was used, as it was upwind from the station. Monitoring of control site W continued since it was still normal to the wind direction.

The results of the monitoring are shown in Table 10.

[1] Counted by a member of the monitoring team.

TABLE 10
HAYWARD BART STATION AND CONTROL SITES CO MONITORING RESULTS
(concentrations in parts per million)

Hours	Ecolyzer Site Average	Ecolyzer Site Peak	Profile A Average	Profile A Peak	Control W Average	Control W Peak	Control X Average	Control X Peak	Control Y Average	Control Y Peak	Impact Site M Average
0600-0700	3.5	15.0	6.0	6.5	3.8	4.0	4.0	4.0	-	-	-
0700-0800	8.0	16.0	6.5	9.0	3.8	4.5	5.8	6.0	-	-	-
0800-0900	2.0	12.0	2.7	4.0	4.5	4.5	4.0	4.0	-	-	-
1600-1700	2.5	5.0	3.0	4.5	4.5	4.5	-	-	8.5	10.0	3.0
1700-1800	5.0	12.0	5.0	9.0	3.0	3.5	-	-	5.0	7.5	3.0
1800-1900	3.0	7.0	3.5	3.5	2.0	2.0	-	-	7.5	7.5	2.5

North Berkeley

The North Berkeley Station is located in a totally residential area. Figure 2 illustrates the station, its parking lots and the nearby neighborhood streets. The corner of Sacramento and Delaware Streets is the only intersection in the immediate area which is controlled by a traffic signal. There are stop signs on Virginia at Sacramento and on Acton at Delaware Street. Other stop signs are located at the BART station exits on Virginia, Delaware and Acton Streets.

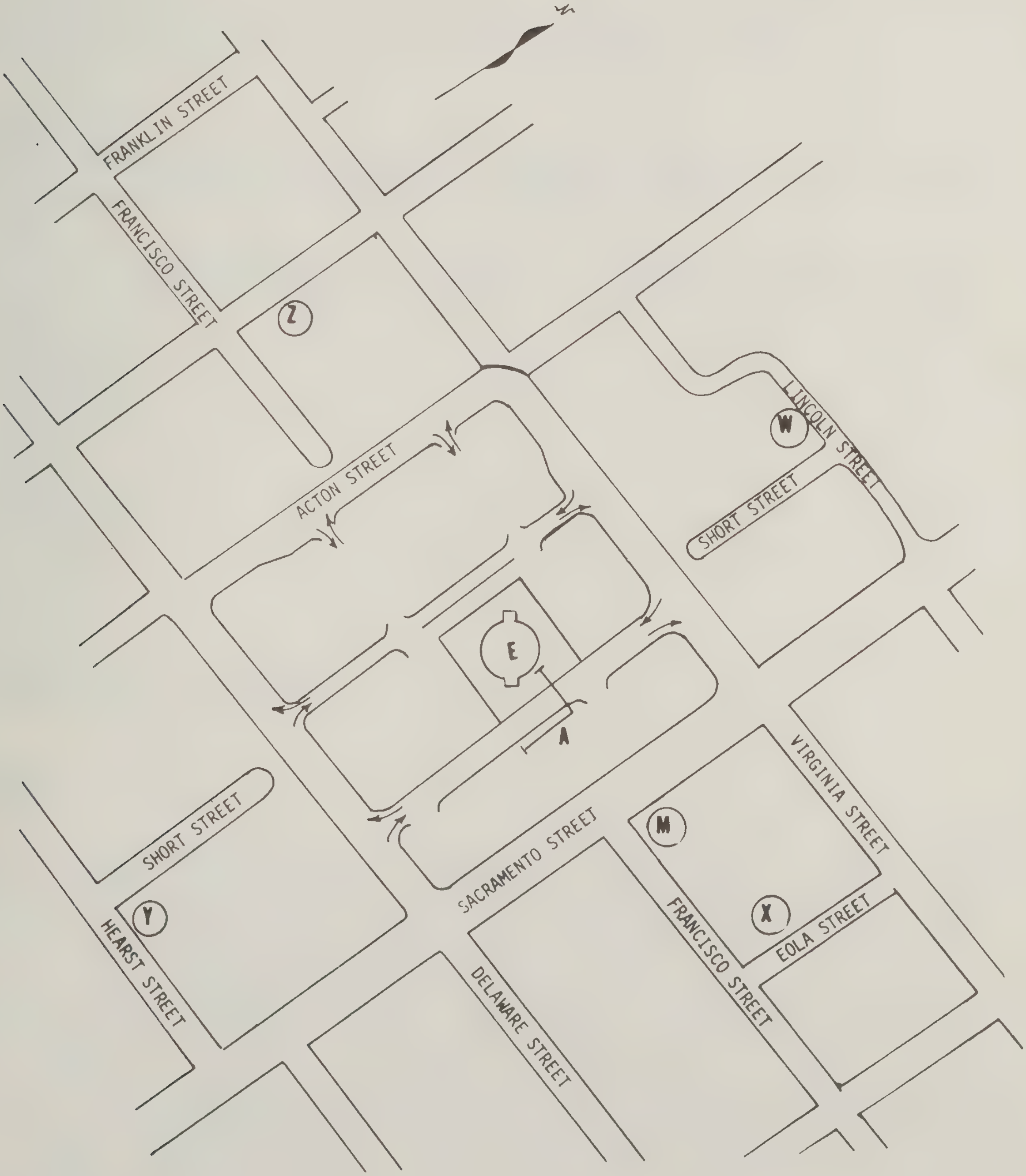
The profile route (marked "A" in Figure 15) started in the lot east of the station[1] on the traffic island separating the parking area from the street. The profile then proceeded northward on the island to the crosswalk directly across from the major station entrance. After crossing the street at the crosswalk, the profile route ended at the station entrance where the Ecolyzer was placed.

Monitoring equipment was set up at the station at 0550 hours and data gathering commenced at 0600 hours. At 0600 there was very little activity at the station. Only a few cars were parked in the lot, and there were not very many patrons getting on and off the trains. The sky had a very thin overcast that was gone by 0800 when the sun became visible. Throughout the morning monitoring period there was a slight breeze from the east. Due to this wind direction, control sites W and X were monitored. Site X was upwind from the station while site W

[1] The reason why this lot was selected instead of the others was because all the buses and "kiss and ride" vehicles utilized the street between the east lot and the station.

FIGURE 15

NORTH BERKELEY BART STATION - CO MONITORING SITES



LEGEND OF SITES:	
E	- Station Entrance
A	- Parking Lot "Walking" Bag Sample
M	- Impact Site (Downwind from BART Station)
W,X,Y,Z	- Control Sites

was normal to the wind direction. There was virtually no traffic at either of these control sites during the morning monitoring period. The afternoon monitoring began at 1530 hours. By that time the wind had shifted 180° and was blowing from the west. As a consequence, the control sites used were switched to W and Z instead.

The impact site M was placed at the corner of Sacramento and Francisco Streets. Results of the monitoring are displayed in Table 11.

TABLE 11
NORTH BERKELEY BART STATION AND CONTROL SITES CO MONITORING RESULTS (concentrations in parts per million)

Hours	Ecoloyzer Site Profile A				Control W		Control X		Control Z		Impact Site M
	Average	Peak	Average	Peak	Average	Peak	Average	Peak	Average	Peak	Average
0600-0700	4.0	7.0	6.0	9.5	4.5	5.0	3.0	3.0	-	-	-
0700-0800	9.5	23.0	8.0	12.0	8.5	11.0	5.0	6.0	-	-	-
0800-0900	10.5	22.0	10.5	12.0	12.5	14.0	8.5	11.0	-	-	-
1530-1600	1.5	2.5			1.0	1.0	-	-	-	-	2.5
1600-1700	2.0	4.0	2.1	3.0	2.0	2.5	-	-	1.5	1.5	4.5
1700-1800	1.5	2.5	1.9	2.5	2.0	2.5	-	-	1.5	1.5	3.5

TRAFFIC MONITORING

General

Traffic count data for both the Hayward and North Berkeley BART parking lots during the carbon monoxide monitoring periods were provided by the Metropolitan Transportation Commission. Each parking lot had a traffic counter position placed at every entrance and exit. The locations of the positions are designated by Roman numerals in Figures 16 and 17. It should be noted that each position, depending on whether it was situated at an entrance, exit or entrance/exit location, consisted of either one or two mechanical counters. For example, at the Hayward BART facility, position I was located at an exit and thus had one counter while position IV was located at an entrance/exit and thus had two counters, one for incoming and one for outgoing vehicles. Table 12 details the number of counters at each position.

FIGURE 16
HAYWARD BART STATION - TRAFFIC MONITORING SITES

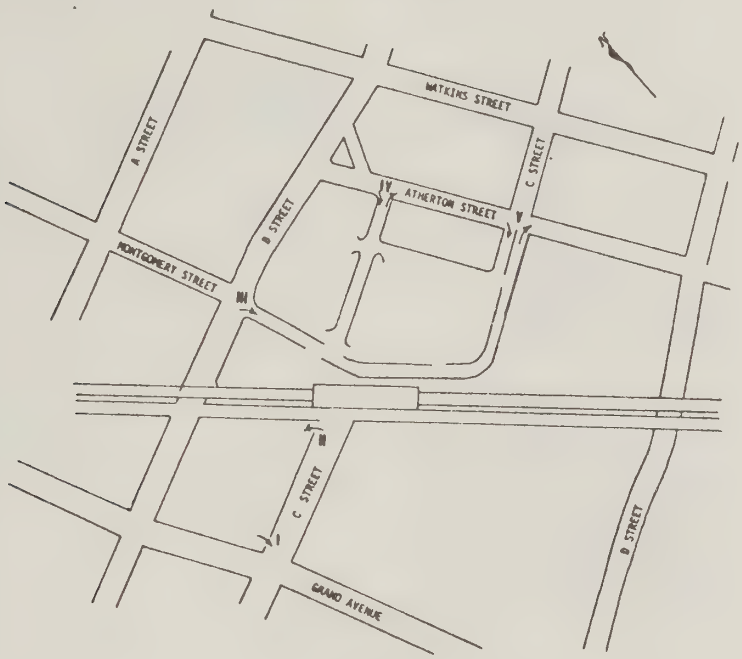


FIGURE 17
NORTH BERKELEY BART STATION - TRAFFIC MONITORING SITES

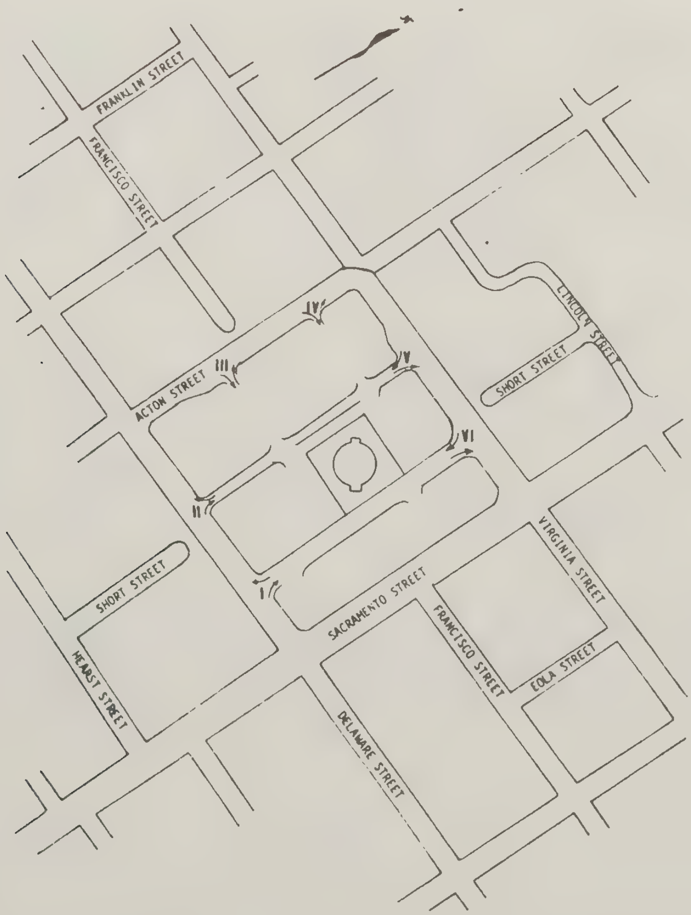


TABLE 12
TRAFFIC COUNTER POSITIONS

BART Facility	Traffic Counter Position Number	Location	Number of Counters
Hayward	I	Exit	1
	II	Entrance	1
	III	Entrance	1
	IV	Entrance/Exit	2
	V	Entrance/Exit	2
North Berkeley	I	Entrance/Exit	2
	II	Entrance/Exit	2
	III	Entrance/Exit	2
	IV	Entrance/Exit	2
	V	Entrance/Exit	2
	VI	Entrance/Exit	2

A record is thus available for all incoming ("IN") and outgoing ("OUT") vehicle activity in each parking area. The counters were set to record traffic activity at six-minute intervals. This data was summed to give the amount of activity during each hour at each counter. The difference between the total number of "IN" and "OUT" vehicles at all counters during any hour yields the number of vehicles which have remained in the station area and are hence presumed to be parked.

Unfortunately, data from one counter at both Hayward and North Berkeley were not available. The amount of activity at these counters had to be constructed using data from the other counters and several simplifying assumptions. Discrepancies were also discovered in the course of analyzing the data. The manner in which the missing data and discrepancies were dealt with is detailed in the subsection, Data Analysis.

The results of the traffic monitoring program are shown in Tables 13 and 14. At the Hayward Station from 0800 hours to 1900 hours, the total number of vehicles parked in the lots exceeds the capacity of the lot (946 spaces). The immediate suspicion was that the traffic count data in

TABLE 13
HOURLY SUMMARY OF VEHICLE ACTIVITY AT THE NORTH BERKELEY BART FACILITY ON FEBRUARY 27, 1975

	"IN"			"OUT"	
Hourly Period	# of Vehicles Entering During Hourly Period	Total # of Vehicles Entering	Adjusted Total # of Vehicles Entering	# of Vehicles Exiting	Total # of Vehicles Exiting
2400-0100	14	14	40	19	19
0100-0200	3	17	43	8	27
0200-0300	1	18	44	6	33
0300-0400	0	18	44	8	41
0400-0500	5	23	49	4	45
0500-0600	20	43	69	14	59
0600-0700	90	133	159	42	101
0700-0800	174	307	333	86	187
0800-0900	209	516	542	74	267
0900-1000	120	636	662	58	319
1000-1100	75	711	737	80	399
1100-1200	89	800	826	88	487
1200-1300	126	926	952	92	579
1300-1400	84	1010	1036	100	679
1400-1500	84	1094	1120	103	782
1500-1600	85	1179	1205	135	917
1600-1700	93	1272	1298	169	1086
1700-1800	121	1393	1419	171	1257
1800-1900	96	1489	1515	113	1370
1900-2000	55	1544	1570	68	1438
2000-2100	18	1562	1588	68	1506
2100-2200	14	1576	1602	50	1556
2200-2300	15	1591	1617	20	1576
2300-2400	6	1597	1623	21	1597

TABLE 14
HOURLY SUMMARY OF VEHICLE ACTIVITY AT THE HAYWARD BART FACILITY ON FEBRUARY 26, 1975

	"IN"			"OUT"	
Hourly Period	# of Vehicles Entering During Hourly Period	Total # of Vehicles Entering	Adjusted Total # of Vehicles Entering*	# of Vehicles Exiting	Total # of Vehicles Exiting
2400-0100	4	4	90	26	26
0100-0200	5	9	95	23	49
0200-0300	3	12	98	13	62
0300-0400	2	14	100	11	73
0400-0500	6	20	106	7	80
0500-0600	77	97	183	3	83
0600-0700	333	430	516	9	92
0700-0800	586	1016	1102	18	110
0800-0900	243	1259	1345	64	174
0900-1000	189	1448	1534	207	381
1000-1100	98	1546	1632	252	633
1100-1200	116	1662	1748	186	819
1200-1300	129	1791	1877	103	922
1300-1400	112	1903	1989	89	1011
1400-1500	121	2024	2110	109	1120
1500-1600	141	2165	2251	119	1239
1600-1700	192	2357	2443	166	1405
1700-1800	319	2676	2762	329	1734
1800-1900	164	2840	2926	200	1934
1900-2000	86	2926	3012	313	2247
2000-2100	43	2969	3055	420	2667
2100-2200	30	2999	3085	210	2877
2200-2300	24	3023	3109	98	2975
2300-2400	16	3039	3125	64	3039

*According to an observation of 100 vehicles in the lots at 0600

some way did not account for all exiting traffic. This was supported by examining the data at the "OUT" counter at the Atherton and C Street exit between the hours of 0700 and 0800. During this period, four vehicles were recorded as outgoing. However, this exit is the one used by feeder buses to the station. Checking the AC Transit's bus schedules, at least 43 buses were supposed to enter and leave the station between 0700 and 0800 hours.

Data Analysis

At both the Hayward and North Berkeley BART facilities, data was missing from a counter placed at parking lot entrances ("IN" traffic counters). These "IN" counters were at position IV in Hayward and position III in North Berkeley (Figures 16 and 17). To reconstruct the missing data, the following method was employed.

Over a 24-hour period, a parking lot was assumed to have an equal amount of "IN" and "OUT" activity. In the case of the BART lots, the summation of daily activity at all the "IN" counters should equal the summation of daily activity at all "OUT" counters. Therefore, if only one "IN" counter is missing, the summation of daily activity at that counter can be determined from

$$\sum_{0100 \text{ hrs}}^{2400 \text{ hrs}} \text{all "OUT" counters} - \sum_{0100 \text{ hrs}}^{2400 \text{ hrs}} \text{all } \underline{\text{available}} \text{ "IN" counters}$$

$$= \sum_{0100 \text{ hrs}}^{2400 \text{ hrs}} \text{missing "IN" counters}$$

The <u>hourly</u> distribution of the derived "IN" activity is assumed to be the same as the hourly distribution of daily "IN" activity at a nearby counter. At Hayward the hourly distribution of traffic at the "IN" traffic lane at position V was used to reconstruct the hourly distribution at the "IN" traffic lane at position IV. At North Berkeley position IV "IN" data was used in the reconstruction. The relationship utilized was:

Hayward: Position IV "IN" activity at hour H =

$$\left[\frac{\text{Total daily "IN" traffic at position IV}}{\text{Total daily "IN" traffic at position V}}\right] \times \left[\text{Position V "IN" activity at hour H}\right]$$

North Berkeley: Position III "IN" activity at hour H =

$$\left[\frac{\text{Total daily "IN" traffic at position III}}{\text{Total daily "IN" traffic at position IV}}\right] \times \left[\text{Position IV "IN" activity at hour H}\right]$$

A discrepancy was discovered regarding the count data for the isolated parking lot west of the Hayward BART station. At this lot traffic counter, position I was located at an exit while position II was at an entrance. However, for February 26 (the day on which the carbon monoxide monitoring occurred), position I showed 460 vehicles leaving the lot while position II showed 238 vehicles entering. This aberration in data was apparently due to the fact that the exit, being closer to Grand Avenue (a major thoroughfare) than the proper entrance, is more accessible than the proper entrance and therefore was used as an illegal entry point to the lot.

To correct this discrepancy, the assumption was again made that a parking lot has an equal amount of "IN" and "OUT" activity over a 24-hour period. In this case, the data can be correctly portioned between "IN" and "OUT" activity by taking the sum of the activity at the two positions and dividing by 2. Thus, for February 26, the actual amount of daily "IN" or "OUT" activity is:

$$\frac{460 + 238}{2} = 349$$

The hourly distribution of traffic in either direction for this west parking lot is determined from the following two relationships:

Position I "OUT" activity at hour H =

$$\left[\frac{\text{Adjusted daily "OUT" activity at position I}}{\text{Unadjusted daily "OUT" activity at position I}}\right] \times \left[\text{Unadjusted "OUT" activity at position I for hour H}\right]$$

Position II "IN" activity at hour H =

$$\left[\frac{\text{Adjusted daily "IN" activity at position II}}{\text{Unadjusted daily "IN" activity at position II}}\right] \times$$

$$\left[\text{Unadjusted "IN" activity at position I for hour H}\right]$$

The number of vehicles parked in the lots at the end of any given hour H is determined from: (number of vehicles parked in the lots at the end of hour H-1) + (total number of vehicles entering between hour H-1 and H) - (total number of vehicles leaving between hours H-1 and H).

From the automatic counter data the number of vehicles entering and exiting between hours H-1 and H can be obtained. However, to obtain the number of vehicles parked in the lots at the end of hour H-1, an initial count of parked vehicles has to be available. TRW monitoring personnel performed a vehicle count at both the Hayward and North Berkeley stations before they commenced monitoring. At 0600 hours on February 26, there were 100 vehicles at Hayward and at 0600 on February 27, there were 10 vehicles at Berkeley. Automatic counter data were thus adjusted at 0600 hours to account for these vehicles.

Tables 13 and 14 present the original and adjusted count data. The difference between the "Adjusted Total Number of Vehicles Entering" and "Total Number of Vehicles Exiting" at 0600 hours equals the number of cars observed in the lot at that time. The difference between the "Adjusted Total Number of Vehicles Entering" and the "Total Number of Vehicles Entering" yields a constant value K which is applied throughout the entire 24-hour period. Therefore, for any given hour, the column "Adjusted Total Number of Vehicles Entering" = "Total Number of Vehicles Entering" + K.

XII. REFERENCES

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MICROCLIMATE

XIII. DEFINITION AND SCOPE

The construction of a rapid transit system such as BART has resulted in an alteration of existing land use patterns in order to locate station facilities, parking lots, guideways, and other BART-related structures. Neighborhoods which are primarily residential (such as North Berkeley) have witnessed the removal of entire blocks of houses; elevated trackways have been placed where no structures of that nature previously existed. These changes may result in changes to the local microclimate. (Local microclimate refers to meteorological phenomena, such as wind, whose scale of analysis is in the order of magnitude ranging from a few square meters to a square kilometer.)

The objective of this study is to identify the impact of BART facilities on local microclimate. Facilities under consideration are the station areas and elevated rail guideway and stations. The microclimatological features examined include wind, temperature, and shadows.

The following issues were examined in meeting the study's objective:

- The effect, if any, of BART structures on local wind conditions
- The effect of radiated heat from BART parking facilities
- The effect of BART ventilation shafts on ambient temperatures
- The effect of BART structures in creating daytime shadows

Temperatures in the immediate vicinity of a BART station may be influenced by the heat characteristics of asphalt and/or concrete pavement (e.g., from a parking lot) and by heat generated by automobile traffic entering and moving about the station. Local wind may be influenced by the presence of BART structures such as the stations or aerial lines and by the open spaces created by the station parking lots. Daytime shadows cast by BART structures may affect ambient air temperature.

The impact of BART structures on macro-scale meteorology (i.e., the entire Bay Area) was not examined, as the nature and extent of these structures were considered to be negligible in affecting regionwide temperature and wind conditions.

XIV. STUDY STRATEGY AND ASSESSMENT METHODS

The study strategy employed in evaluating the impact of BART structures on wind conditions was trained observer judgment. These judgments were made on the basis of field observations taken at eight locations (Figure 18). The BART facilities assessed and the reason for their selection as representative conditions are enumerated below.

- Civic Center Station in San Francisco - the removal of buildings to form the Civic Center Plaza in conjunction with BART construction may have altered the wind patterns which have in the past been affected by the buildings.

- Daly City Station - the clearing of structures to form one of the larger parking areas in the BART system may have caused increased wind velocities (i.e., no obstructions to the wind presently exist).

- El Cerrito Plaza Station - this is an example of an elevated station area located at the edge of a parking lot. As winds blow through the parking area and are funneled under the station, the wind velocity may increase.

- North Berkeley Station - four blocks of single-family dwellings were removed to create an open parking area. The BART station entrance is located approximately in the center of the parking area. Wind blowing through the parking area and around the station facility may cause turbulence on the downwind side of the lot.

- Ashby Station - this station is unique in that the parking area is depressed.

- Grove Street (Oakland) trackway - the track emerges from underground and continues on an elevated structure. Wind may be channeled beneath the guideway and increase in velocity.

- Bay Fair Station - this station is built on a berm which ranges from 10 feet to 20 feet in height. Thus, the berm might act as a "wind break" for structures downwind of the station.

- Hayward Station - the station structure is approximately 35 feet high and 300 feet long and again might act as a "wind break."

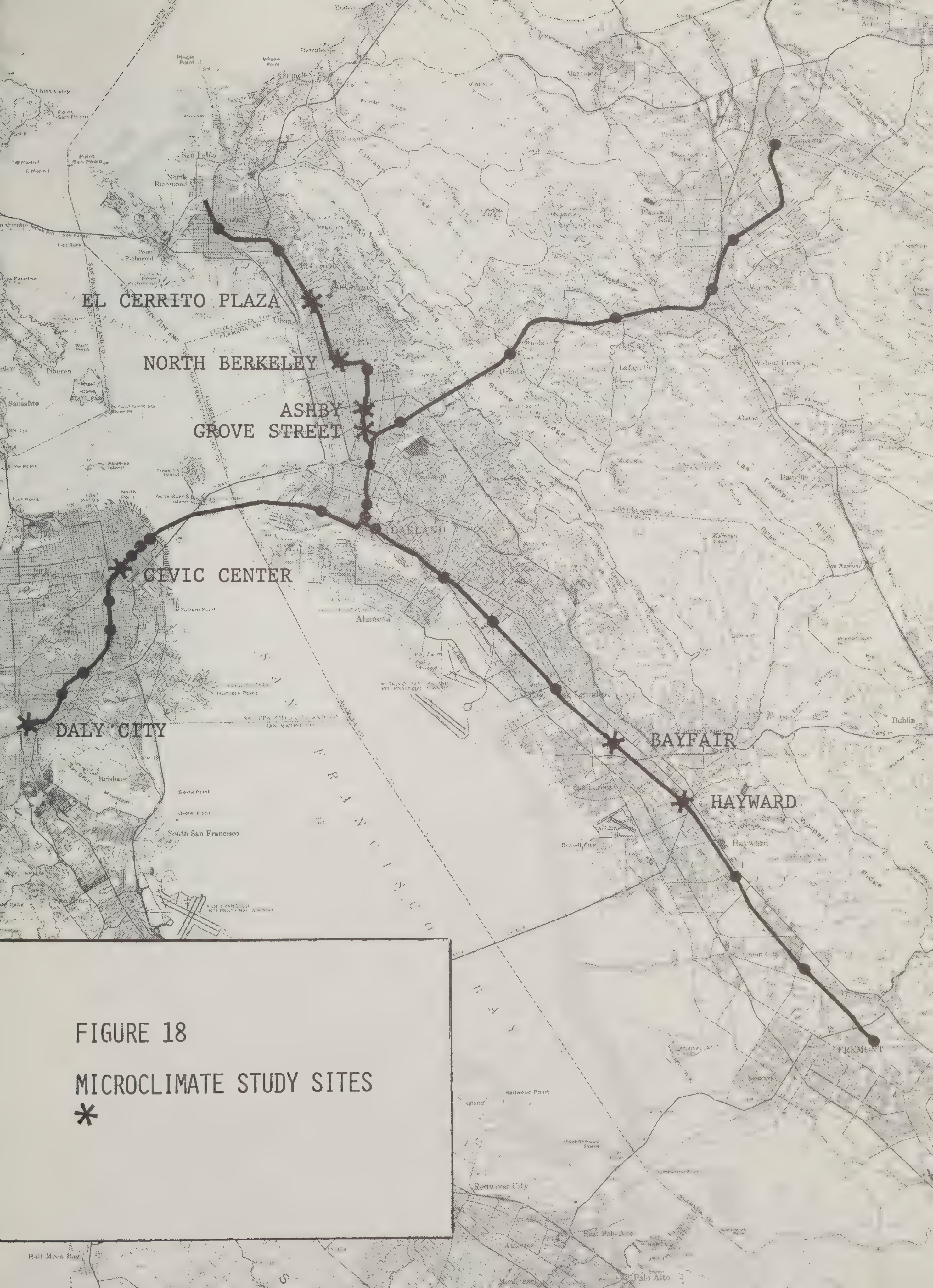


FIGURE 18

MICROCLIMATE STUDY SITES
*

XV. FINDINGS

AMBIENT WIND CONDITIONS

Westerly and northwesterly are the most common directions of winds in the San Francisco Bay Area during the year as a whole, occurring altogether about 50% of the time. Calm and light variable winds occur about 25% of the time, and measurable winds from all other directions occur the remaining 25% of the time (Bay Area Air Pollution Control District, 1970).

The westerly and northwesterly winds are most predominant during the spring and summer. Typically, in the early morning hours they start out at speeds of 5 MPH or less, then increase to about 15 MPH before noon and 15 to 22 MPH by mid-afternoon. During afternoon hours, occasional gusts between 25 MPH and 30 MPH are not uncommon, particularly in San Francisco. Towards dark, the winds slacken sharply, diminishing to 8 to 12 MPH by 9 PM.

WIND FLOW AROUND AND BENEATH BART FACILITIES

The effects of obstacles of various sizes and configurations upon wind flow are treated both analytically and experimentally as classic problems in aerodynamics. Throughout these studies the air flow prior to impact is generally considered laminar, corresponding to the structure of air with stable vertical temperature distribution. Initial laminar flow will therefore be an assumption of the following discussion of BART structure effects on the wind.

While air is considered an elastic medium, the wind flow does not immediately reconstitute itself after passing an obstacle but undergoes disturbances that propagate in the lee flow for a distance beyond the obstacle. This "wake effect" tends to dampen quickly under light to moderate wind conditions (say, under 20 MPH), but with stronger winds vortices may degenerate into chaotic motions that persist downwind for distances many times the cross-section of the obstacle (Schlichting, 1955). Wind patterns also depend upon the width and shape of the obstacle and the angle of incident wind flow with respect to the obstructing surface.

In the Grove Street area, BART is on elevated structure. The supporting structure is substantial compared with its relatively low clearance above the street level. In this area, strong westerly winds are constricted as they pass under the elevated trackway, and wind velocities, perhaps as much as 25% higher than the average, could occur in this area.

The channeling of winds along city streets is an effect that is readily observed, particularly along street canyons between rows of tall buildings. As the wind of a given average velocity flows across the waffle pattern of city streets, wind velocities in the streets aligned with the incident wind are greater than average, while winds on the cross streets are less than average and often variable in direction. The contrasting effects observed in the downwind and cross directions depend upon building height and street width. The contrast is generally more evident in downtown areas compared with residential, particularly suburban areas.

The removal of buildings to form the Civic Center Plaza in connection with BART construction permits winds from the west to north sectors to be reconstituted over the open plaza space. As air moves to cross Market Street at 8th Street alongside the two BART entrances, it is constricted between the buildings on the corner and the wind speed appears to increase. Creation of the plaza has probably turned the west side of the 8th and Market Street intersection into a windier corner than it had been.

WIND FLOW INTO OPEN AREAS

Wind that has been disturbed by passage over obstacles, or wind that has been channelized by passage along city streets, tends to become reconstituted after re-entering an open area. This effect could occur at a number of BART station parking lots, many of which were built after removal of houses or other structures. Buildings facing the wind at the edge of the parking lots could now be subjected to wind velocities averaging as much as 30% to 50% higher than they had previously experienced.

TUNNEL VENTS

Discussion of BART's ventilation facilities with staff personnel at BART revealed that all existing vents are of the negative pressure variety--i.e, they are intake vents. From observation of air flow in the vicinity of these vents at the North Berkeley and Hayward Stations, no noticeable impact on ambient air temperatures was detected, nor was localized turbulence created.

TEMPERATURE

Temperature measurements were made during the two-day (February) period when the local air quality monitoring was done. The results indicate that there are no significant differences between air temperature over parking areas (ground covered with asphalt and/or concrete) as opposed to uncovered ground (Table 15). However, during periods of warmer weather (summer time) it is possible greater differences between covered and uncovered ground would be observed.

TABLE 15
AMBIENT AIR TEMPERATURE MEASUREMENTS (in degrees Fahrenheit)

	Hayward Station				North Berkeley Station			
	Parking Lot		Uncovered Ground		Parking Lot		Uncovered Ground	
Time	2' elevation	6' elevation	2' elevation	6' elevation	2' elevation	6' elevation	2' elevation	6' elevation
0900	54°	54°	54°	54°	56°	56°	59°	59°
1530	66°	66°	65°	65°	67°	67°	66°	66°
1755	--	--	--	--	62°	62°	62°	62°
1900	56°	56°	56°	56°	--	--	--	--

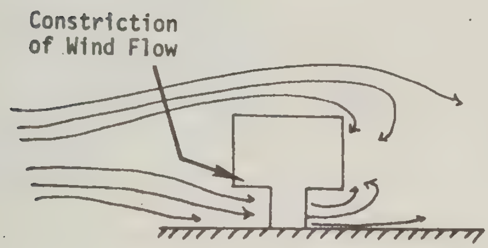
SHADOWS

Visual inspection and measurement of the temperatures in the daytime shadow areas created by BART structures indicate that these shadows have no perceivable impact on lowering temperatures.

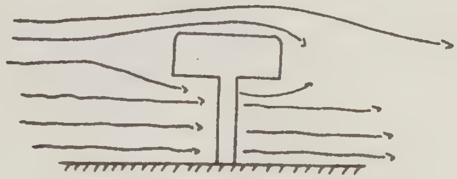
XVI. GENERAL DESIGN CONSIDERATIONS

The observations of BART indicate certain principles worthy of consideration relative to the effect of wind on station and guideway design. Wind velocities will increase if air is forced through a narrow and constricting opening, such as can occur beneath elevated station areas and guideways.

less desirable

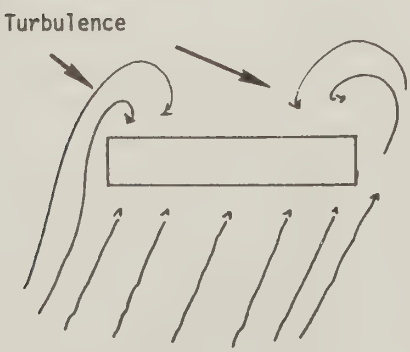


more desirable



On the other hand, if a solid structure (such as a berm) is placed perpendicular to the wind direction, turbulence will develop on the downwind side of the structure.

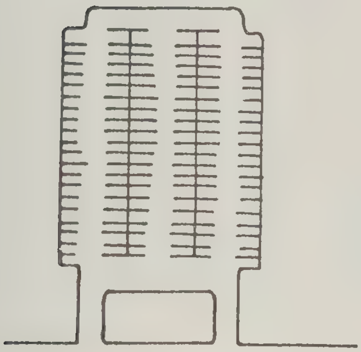
less desirable



more desirable

Instead of one or two extremely large parking lots, consideration should be given to a group of smaller parking areas landscaped with trees to prevent the reconstitution of wind flow.

less desirable



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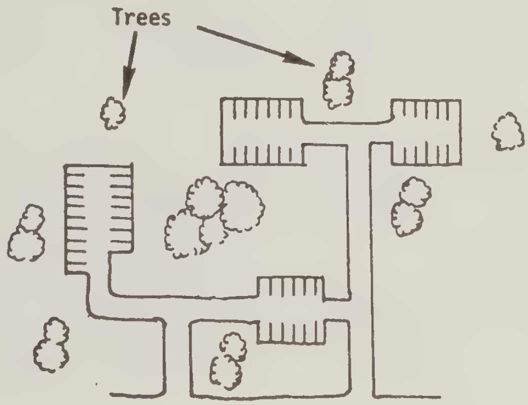

XVII. METHODOLOGY

As mentioned in Chapter XIV, the methodology employed in assessing the impact of BART structures on wind flow was the expert judgment of a trained observer. No instruments were used. The visits to the stations were made over a two-day period, April 10 and 11, 1975. Weather conditions on the 10th were fair and quite breezy, while clear skies and light wind conditions prevailed on the 11th. Observational notes on the individual BART sites are presented below.

Temperature measurements of ambient air temperatures over BART parking lots and uncovered ground at the Hayward and North Berkeley Stations were made on the days which the local air quality monitoring was done (February 26 and 27, 1975). The instrument used was a Beckman Model M4 fast response electric thermometer. This instrument was also used in measuring temperatures in the daytime shadow areas created by BART structures.

OBSERVATIONAL NOTES ON INDIVIDUAL BART SITES

- Civic Center (San Francisco) 4/10/75 3:50 p.m.
  Weather: Fair; scattered strato-cumulus: temperature 56° F; wind estimated WSW at 18 miles/hour, gusting to 25 miles/hour.

  Effects: Strongest winds at corner of 8th and Market, west side of street.

- Daly City 4/10/75 4:30 p.m.
  Weather: Partly cloudy; broken strato-cumulus; temperature 53° F; wind estimated SW at 20 miles/hour, gusting to 28 miles/hour.

  Station: Platform oriented NE - SW. East half about at street level, west half elevated to about level of house tops across John Daly Blvd. Glass shielding at platform.

  Vicinity: Mostly residential. Parking lot on east side of street has sheer wall 10 ft. high at NE end and up to 30 ft. high at SW end.

  Effects: Station appears to have added minimal effect on wind patterns.

- El Cerrito Plaza 4/10/75 6:00 p.m.
Weather: Fair; scattered strato-cumulus; temperature 56° F; wind estimated WSW at 15 miles/hour, gusting to 22 miles/hour.

  Station: Platform oriented NNW to SSE, elevated with about 20 feet clearance.

  Vicinity: Shopping center and residences.

  Effects: Parking lot west of station allows wind to regenerate after passing hills and low buildings west of the station. Upper level of station (platform) effectively screens against westerly wind flow, forcing some air under platform, resulting in increased wind speed, possibly 20% higher than over parking lot. This wind continues across Richmond Street and impacts on houses that line the block north of Fairmount Street.

- North Berkeley 4/10/75 6:30 p.m.
Weather: Fair; scattered strato-cumulus; temperature 52° F; wind estimated SWS at 14 miles/hour, gusting to 19 miles/hour.

  Station: Cake-shaped open to WSW - ENE - SSE - NNW on mound about 175 feet square with border of ground cover 20 ft. Parking areas on all sides at street level, with nearest houses north of station.

  Vicinity: Generally residential.

  Effects: Wind probably reconstituted during passage over west parking lot but slightly disturbed by passage over station mound. Effect is minimal due to smooth, dome-like profile. Houses east of station more exposed than previously due to creation of parking lot, but all structures are low and difference before and after appears insignificant.

- Ashby 4/10/75 6:50 p.m.
Weather: Fair; scattered strato-cumulus; temperature 52° F; wind estimated WSW at 11 miles/hour, gusting to 16 miles/hour.

  Station: Oriented NNE - SSW, in hollow with Adeline Street passing over at street level. Parking lots to west and east in bowl-shaped ground from station entrance level. Tracks depressed below station level but not entirely underground.

  Vicinity: Residential row houses and stores at Adeline Street level.

  Effects: Wind drops off within parking lot bowl to about 25% less than at street level. Airflow at street levels thus apparently little disturbed by BART structures.

- Grove Street 4/10/75 7:10 p.m.
Weather: Fair; scattered strato-cumulus; temperature 52° F; wind estimated WSW at 10 miles/hour, but under emerging tracks may be gusting to 18 miles/hour.

  Station: None. Tracks emerge from underground south of Alcatraz Avenue and rise to elevated along Grove Street in Oakland. Clearance at 62nd Street only about 14 feet high with more massive structure supporting rising tracks.

  Vicinity: Some commercial but predominantly residential along Grove Street.

  Effects: Westerly wind has Bernoulli effect under tracks at 62nd Street and accelerated wind, about 25% higher than average, impacts against store glass windows of buildings on northeast corner of 62nd and Grove Streets. Building on southeast corner of 62nd and Grove Streets appears to have far less impact.

- Bay Fair 4/11/75 9:35 a.m.
Weather: Clear; temperature 53° F; wind estimated WNW at 5 miles/hour.

  Station: Elevated, oriented NW - SE, on berm with parallel single railroad tracks at lower level to west of station.

  Vicinity: Low residential structures to west and east of station; shopping center to northeast about 0.1 to 0.2 miles; hills to east about 0.75 miles.

Effects: Parking lot to east is somewhat screened by station. Reconstituted wind then impacts on shopping center structures. Effects of BART insignificant. Berm about 10 to 20 ft. high supporting tracks effectively screen houses to east from strong west winds. However, berm replaces previous row of houses that provided similar though somewhat less protection.

- Hayward 4/11/75 10:20 a.m.
  Weather: Clear; temperature 54° F; wind estimated WNW at 3 miles/hour.

  Station: Elevated platform; glass screening about 300 ft; oriented NW - SE.

  Vicinity: Industrial warehouses especially to west; nearest residential area is to north about 0.1 mile from station.

  Effects: Most wind flow may parallel tracks and station; hence effects are insignificant. Some screening of SW wind by station structure about 35 ft. high and 300 ft. in length of enclosed area.

ENVIRONMENT PROJECT PHASE I DOCUMENTATION

- Interpretive Summary*
- Environmental Impacts of BART* Interim Service Findings (1976)
- Acoustic Impacts of BART* Interim Service Findings (1976)
- Impacts of BART on Air Quality* Interim Service Findings (1976)
- Impacts of BART on the Natural Environment* Interim Service Findings (1976)
- Impacts of BART on the Social Environment* Interim Service Findings (1976)
- Impacts of BART on Visual Quality* Interim Service Findings (1976)
- Theory Background for Study of BART's Impacts (1976)
- Pre-BART Data Analysis (1975)
- Community Monitoring (1976)
- BART and Its Environment: Descriptive Data (1976)
- Research Plan* (1975)

STUDY PARTICIPANTS

Consultant Team
Gruen Associates, Inc.
De Leuw, Cather & Company
Bolt Beranek & Newman, Inc.
TRW, Inc.
Curtis Associates
Dr. Frances M. Carp
Dr. Martin Wachs
Dr. Eugene Grigsby

Performing Organization
Metropolitan Transportation Commission

Sponsoring Organization
United States Department of Transportation
United States Department of Housing and Urban Development

*** Document is available to the public through the National Technical Information Service (NTIS), Springfield, Virginia 22151. Other documents are MTC internal working papers.**